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Partner selection and resource exchange in cooperative network

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Abstract- **Resource sharing for improved performance is a key factor in practical realization of cooperative communication networks. This paper presents a choice of suitable partner for optimizing the resources and thereby, strengthening the cooperation in the wireless network. Nodes in the network forms a pair to compensate for each other's deficiency. These paired nodes share the resources owned by them amongst the pair and hence naturally remain in cooperation. This is achieved without the need of any outside stimulation like pricing, credit or reputation index. Exchanging the resources is an attractive technique to achieve mutual benefits and encourage cooperation among the nodes. In the proposed work nodes cooperating by exchanging bandwidth with relaying power. Simulation results show that the source node can increase its data rate in the range of 71% to 97% by assigning some fraction of its bandwidth to relay. The relay also earn benefit by getting additional bandwidth in terms of increase in its data rate from 12.5% to 97 %. Based on this, an algorithm is developed for partner selection. The algorithm produces sub-optimal results as it considers the benefit of source and relay individually. It is found that in this framework, the sub-optimal procedure is more suitable.**

Keywords: Cooperation stimulation, resource exchange, cooperation negotiation, amplify & forward

I. INTRODUCTION

Cooperative communication is a method which enables wireless users to transmit their data to the destination in cooperation with each other. By taking the advantage of broadcast nature of wireless channel, cooperating nodes can form distributed antenna system and get benefit of spatial diversity gain. Day by day, the variety of new services are emerging and demand of bandwidth is increasing. In this context the concept of cooperation is explored further to make it practically realizable. Cooperative communication has shown its potential in increasing link reliability, coverage and throughput using the limited resources. [1-2]

There are many challenges in the way to realize this concept into commercial system. Some of these challenges are increased interference and traffic due to duplication of transmission, increased overheads and latency in finding suitable relay [3]. Many of these issues can be resolved by applying efficient resource allocation mechanism. Resource allocation for cooperative network has been discussed in [4-6]. In our earlier work [7-8], utility function based resource optimization schemes suitable for infrastructure base centrally controlled cooperative network has been presented. In the centralized network, global channel information is necessary for optimizing performance of cooperative network through resource allocation. The computational complexity grows with the size of the network. Further, it is very optimistic to assume that a wireless node altruistically help other wireless node using own resources, unless their service provider program it to do so. To encourage nodes to cooperate with each other without compulsion from service provider, some stimulating mechanism is needed. The Price based mechanism [9-11] and The Reputation based mechanism [12-13] are widely discussed in the literature. The node acting as relay is paid virtual money for cooperating with source in price based mechanism. Each node having good channel condition with destination can earn virtual money which can be used to buy help of others in need. In reputation based mechanism, a reputation index is maintained. The index of the node helping others would increase and the node having higher index would get cooperation from other nodes. The selfish node could easily be identified and denied cooperation. Both these techniques require additional tamper proof hardware and maintenance of account of virtual money or reputation index. It would be very difficult task to maintain such account for mobile nodes in large network.

In this paper, a distributed mechanism having low overhead resource exchange, capable of stimulating cooperation and optimizing resources is proposed. A node in need of extra bandwidth shows its readiness to become relay for some source. In exchange it expects some part of source's bandwidth to carry on its own transmission. The proposed scheme encourages nodes to cooperate based on mutual benefit. An advanced heterogeneous data network consisting of variety of nodes, engaged in delay tolerant applications is considered. The benefits of mutual cooperation has been demonstrated. If nodes find their partner in completely independent manner, it requires fewer overheads and less computational complexity but the performance would be sub-optimal. If central controller is involved in match making process, optimal pairs can be made to maximize the benefit of cooperation. The trade-off between distributed control and central control has also been demonstrated.

Next section consists of system model and resource exchange mechanism. Simulation environment and results are discussed in section III. Section IV describes the sub-optimal and optimal procedure for partner selection, followed by conclusion in section V.

II. SYSTEM MODEL

For evolving the mechanism, a simple wireless network consisting of three nodes is considered. The nodes use Decode and Forward protocol for cooperative communication. It is assumed that nodes are capable of making decision about cooperation, degree of cooperation and resource optimization by sensing the channel locally. Node *S, R* and *D* present source, relay and destination, respectively. Node *S* and *R* allocated W_s Hz and W_r Hz of bandwidth. It is assumed that source *S* wants to communicate with *D* and at the same time relay *R* also want to communicate with the same destination.

Table I Notations

P_s	Source Power
P_r	Relay Power
Ws	Source Bandwidth
Wr	Relay Bandwidth
h_{sd}	Channel gain of S-D link
h_{rd}	Channel gain of R-D link
h_{sr}	Channel gain of S-R link
N_0	Noise power spectral density
α	Portion of bandwidth shared by source with relay
$R_{s,direct}$	Data rate of source without cooperation
R_r	Data rate of relay without cooperation
R_{sr}	Data rate of source with cooperation of relay
$R_{rd,comb}$	Combined data rate of source and relay with cooperation
R_{cr}	Data rate of relay with cooperation

Source *S* requires to achieve a minimum data rate of transmission, *Rs,min* and relay transmits to its destination *D* at the rate of *Rr*. Assuming a scenario with limited power available with source and bad channel condition, it seeks the cooperation from the relay to transmit its signal. The relay do so for source in exchange of source bandwidth with relay power. This scenario creates power-bandwidth exchange cooperation in the network. Table I shows all the notations used in this analytical model.

Let the source has the power of *Ps* units and the relay has power of *Pr* units. Under the condition without any cooperation the maximum capacity that the source and relay can achieve can be given as

$$R_{s,direct} = Ws * log2\,(1 + \frac{P_s * h_{sd}}{N_0 * Ws}) \qquad (1)$$

and

$$R_r = Wr * log2\,(1 + \frac{P_r * h_{rd}}{N_0 * Wr}) \qquad (2)$$

If maximum achievable rate by source $R_{s,direct}$ is less than minimum required rate $R_{s,min}$, the source decides to enter in cooperation with relay. In cooperation mode, source offer a fraction *α* of its bandwidth to relay and transmits its information in the remaining available bandwidth to relay. This signal is decoded by node *R*. It can be decoded correctly if data rate is less than or equal to the capacity of *S-R* link. Thus, the maximum capacity of the link from source to relay under cooperation can be given as

$$R_{sr} = (1 - \alpha) * Ws * log2\,(1 + \frac{P_s\, h_{sr}}{N_0 * (1-\alpha) * Ws}) \qquad (3)$$

Now, relay node R transmits the information of source by re-encoding it along with its own information to the destination node *D*. Thus share its power for re-transmission of source's information. The maximum achievable combined data rate by relay can be given as

$$R_{rd,comb} = (Wr + \alpha Ws) * log2\,(1 + \frac{P_r\, h_{rd}}{N_0 * (Wr + \alpha Ws)}) \quad (4)$$

Out of this data rate, relay ensures *Rs,min* data rate for the source and remaining for itself as

$$R_{s,min} = \min(R_{sr},\ (R_{rd,comb} - R_r)) \qquad (5)$$

Thus, the effective data rate of relay under cooperation would be

$$R_{cr} = (Wr + \alpha Ws) * log2\left(1 + \frac{P_r\, h_{rd}}{N_0 * (Wr + \alpha Ws)}\right) - R_{s,min}$$

(6)

Relay would choose to cooperate with source iff $R_{cr} > R_r$. In this way, the requirement of source node is fulfilled and relay node also find it beneficial to remain in cooperation.

The benefit earned by both the nodes can be computed as

$$R_{s,adv} = R_{s,min} - R_{s,direct} \quad \text{For source} \qquad (7)$$

$$R_{r,adv} = R_{cr} - R_r \quad \text{For relay} \qquad (8)$$

III. SIMULATION ENVIRONMENT, RESULTS AND DISCUSSION

A. Environment

A three node network is considered for simulation. The distance between source *S* and relay *R* is 10m, relay *R* and destination is 10m, and between source *S* and destination *D* is 20m. For the sake of simplicity, path loss channel model with exponent 3 is assumed. The source power P_s, the relay power P_r and the bandwidth available with source are normalized to 1. Bandwidth available with relay varies from 0.1 to 0.9 to observe the various degree of cooperation.

B. Effect of variation of α on Source and Relay data rate

When the bandwidth available with relay is small, its direct data rate without cooperation is also small. It can gain advantage of higher data rate even with the small additional bandwidth it gets from the source. As the bandwidth available with relay increases, the relay demands more bandwidth from the source in return for cooperation. The amount of exchange of resource depends upon already available resources with the nodes. Fig [1] shows the data rate achieved by the source without cooperation (as indicated by dashed line) and data rates achieved by the source during cooperation as a function of fraction α (bandwidth shared by the source to relay). It is visible that the source is capable of achieving the data rate of 0.7 bps/unit of bandwidth without cooperation. It is also evident from the graph that during cooperation when relay has 0.1 unit of bandwidth, the source can maximize the data rate by sharing 45% of its bandwidth with the relay. Similarly when the relay has a bandwidth of 1 unit, the source has to share 62.5% of its bandwidth to achieve maximum data rate. The source has to share sufficient bandwidth with the relay to encourage it to participate in cooperation and gain the benefit of cooperation. If the relay has bandwidth of 0.7, then up to $\alpha = 0.25$, there is no benefit from cooperation. If α rises beyond 0.25, the source achieves higher data rate compared to scenario of no cooperation. The above analysis reflects the source's perspective but for mutual cooperation and benefit, relay's perspective is also to be taken into account. Fig [2] shows relay's data rate with and without cooperation with four different amount of available bandwidth of 0.1, 0.4 0.7 and 1. When bandwidth with relay is 0.1, its data rate without cooperation is 0.724 bps/unit of bandwidth. In the cooperation phase, when source shares a small portion of bandwidth with the relay, there is no increase in relay's data rate.

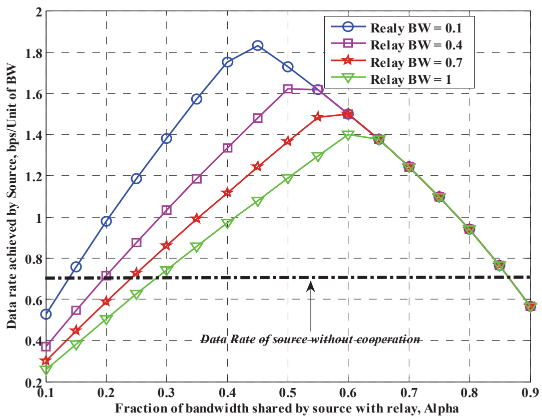

Fig [1] Bandwidth available with relay affects source data rate

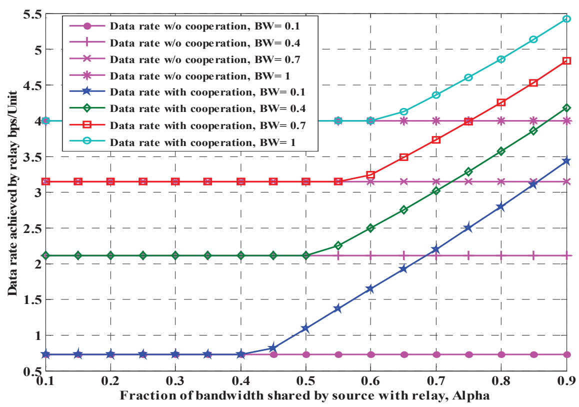

Fig [2] Relay data rate with and with out cooperation

As α increases beyond 0.45 corresponding to relay bandwidth of 0.1, there is increase in relay data rate because of cooperation. Same can be seen from the other values of available relay bandwidth. By comparing Fig [1] and [3], it is observed that for relay bandwidth of 0.1 and $\alpha = 0.45$, the source data rate is maximum but the relay data rate just start increasing. From source's point of view, this is the best point of cooperation but for relay it is not.

In general, for the value of α more than 0.45, relay's data rate start increasing but source's data rate reduces. The point of cooperation must be evaluated which could result in reasonable benefit to both the source and the relay.

C. Benefits achieved by varying α

Eqns (7) and (8) reveal the benefits, both source and relay can achieve individually. As discussed in section in III-B, a point of compromise is required to be determined where both the nodes benefited reasonably. As shown in Fig [3], the feasible point of cooperation can be found at the interaction of the plots based on (7) and (8). It indicates the advantage of data rate obtained by the source and the relay as a function of α. When available bandwidth with the relay is 0.1 unit, the advantage of source and relay would be equal at $\alpha = 0.6$. At this point both the nodes are in benefit and hence their cooperation would be long lasting. If there is no intersection, cooperation would not be feasible. At the point of cooperation source is able to increase the data rate from 0.7 bps/unit to 1.38 bps/unit for the case of relay bandwidth 0.1 unit. The advantage of 0.68 bps/unit reflects 97% increase in the data rate of the source by sparing 60% of available bandwidth. At that point the advantage to relay in terms of data rate is 97%. The same values for relay bandwidth of 1 is 71% and 12.5% for the source and the relay, respectively.

It is very clear from this discussion that when relay has sufficient bandwidth, it would not get much benefit from exchange mechanism. Therefore, for the successful exchange, it is very important to search for the appropriate partner.

In the following section, a distributed partner selection scheme is discussed.

IV. SOURCE-RELAY PARTNER FOR MULTI USER SCENARIO

The partner selection can be initiated by the source node or the relay node. We have considered source-initiated procedure. For creating multiple scenario, 6 source and 3 relays are considered. Source and relay nodes are distributed randomly in the given area so each pair of node faces different channel condition. It is assumed that one relay would make pair with one source only. Further assumed that all the nodes are equipped with same transmission power, all the sources have bandwidth of 1 unit and relay nodes do not have any bandwidth. The data rate achieved by each source-relay pair is shown in table II and III.

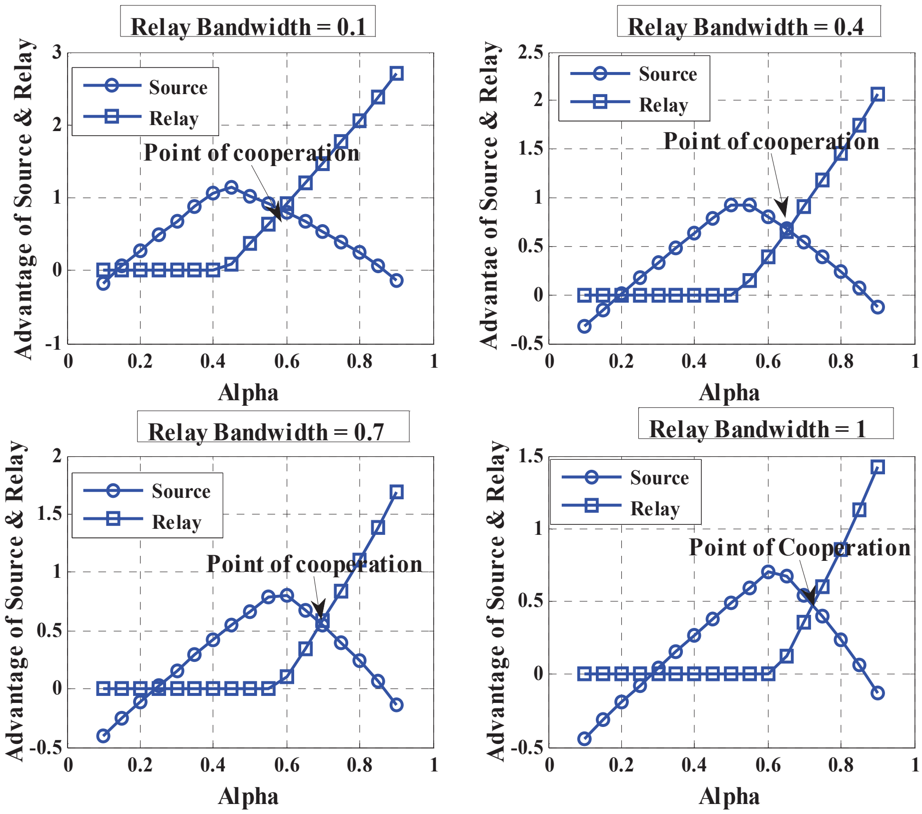

Fig [3] Feasible point of cooperation

A. Procedure for partner selection

(i) Relay nodes send their channel gain with destination using signalling channel
(ii) Sources calculate feasible point of cooperation and decide priority of partner
(iii) Sources send invitation to priority 1 partners. As shown in table II, Source 1, Source 2, and Source 3 send invitation to Relay 3 and Source 4, Source 5, and Source 6 send invitation to Relay 2
(iv) On receiving multiple invitations, relay selects the partner which can give maximum benefit. From table III it can be seen that Relay 3 would select Source 1 and relay 2 would select source 4, out of three invitations
(v) Remaining sources send invitation to second priority partners
(vi) Relays which are already occupied in first round, rejects any further request
(vii) Unoccupied relay selects the best one, if multiple offers are there. Source 5 and Source 6 send invitation to Relay 1, out of which relay 1 selects source 6

The procedure discussed above is fast and the node would quickly find partner from their vicinity. It requires only local channel state information. This procedure is sub-optimal as it consider only source or relay. In place of considering only source or relay, the sum of the data rate of both source and relay is accounted and then based on maximum total data rate, the partners could be selected. This would result in maximizing the data rate of the pair in the cooperation. But this optimal technique needs central controller to gather information of all pairs and then make decision. This in turn increases complexity and overheads. For a dense network and mobile nodes, the sub-optimal technique is more suitable.

Table II: Data rate achieved by source 1- 6 with the help of relay 1 - 3

Table III: Data rate achieved by relay 1-3 with the help of source 1 - 6

	S1	S2	S3	S4	S5	S6
R 1	0.29	0.29	0.29	0.29	0.29	0.30
R 2	0.39	0.39	0.38	0.39	0.38	0.38
R 3	0.49	0.48	0.47	0.51	0.52	0.51

V. CONCLUSION

Cooperation stimulation and resource exchange framework for successful and long lasting cooperation has been presented in this paper. It is seen that with the proposed frame work nodes involved in cooperation by exchanging or sharing the resources can earn benefit and hence, remain in cooperation. An increase in source node data rate in the range of 71% to 97% is achieved by assigning some fraction of the source bandwidth to the relay. The relay node can also earn benefit from additional bandwidth to the tune of 12.5% to 97 %. The less benefit obtained by relay when relay already has sufficient amount of bandwidth indicates that the node would be less interested in cooperation when sufficient resource are there. The benefit of cooperation is significant when relay has less resources of its own and therefore, cooperation would appear attractive to it and it would stick to cooperation. At the end, a procedure for partner selection has been presented. This procedure will produce sub optimal results which may be suitable for dense network and also with mobile nodes from complexity and overhead point of view. An optimal technique, on the other hand, if developed based on global information of all pairs maximizing sum data rate of pair, would require central controller and add to complexity and overhead.

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	S1	S2	S3	S4	S5	S6
No relay	0.22	0.21	0.29	0.25	0.33	0.29
R 1	0.32	0.32	0.35	0.33	0.36	0.35
R 2	0.41	0.41	0.43	0.42	0.44	0.43
R 3	0.44	0.46	0.50	0.34	0.28	0.32

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