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Performance Analysis in Cooperative Communication

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Abstract— In this paper, we have developed a framework for resource allocation in a multi user cooperative wireless network. We have considered centralized and decentralized node-relay assignment with the objective of maximizing the sum throughput. We present an efficient polynomial time centralized assignment algorithm to achieve this objective, and also investigate efficient decentralized schemes that do not require a central authority to perform the allocation. We present a novel message passing based assignment scheme which converges to the optimal value, and present an adapted scheme based on distributed auction theory. We also present a simple sub-optimal greedy assignment strategy and provide empirical data to support its practical significance.

Index Terms—

I. INTRODUCTION

Inthepastfewdecades,wirelesscommunicationhasbeenoneofthetechnicalareaswhichhasexperiencedexponentialadvancementintermsoftechnologyaswellasusers.Thismodeofcommunicationalleviatestheneedofphysicalconnectivityamongcommunicatingentitiesviaexploitingthechannelasasignalcarryingmedium.Thisalsomakescommunicationamongmobiledevicespossible.Themainobjectiveofanymodeofcommunicationistoincreasethedatarateswhilealsomaintaininghighreliability(lower probabilityoferror)ofthedatasentoverthecommunicationlink. However,thewirelesschannelsuffersfromunwantedyetinevitableeffects(e.g.shadowing,pathloss,multipathfadingetc.which makeithardtocommunicatereliablyoverthechannel.Variousdiversitiesofthewirelesschannelsareusedaspotentialsolutionstomitigatesomeofthesechannelimpairments.Spatialdiversityisusedtocombatthedeleteriouseffectsoffadingviatransmittingthe signalsfromdifferentlocations,therebyallowingindependently fadedversionsofthesignalatthereceiver.Theideaofmultipleinputmultipleoutput(MIMO)systemwasproposedtogeneratespatialdiversitybyequippingthewirelessdevicewithmultipleantennas.Howevermanywirelessdevicesarelimitedbysizeandhardwarecomplexitytooneantennaand MIMOisnotrealizableinthesecases.

Cooperativecommunicationsprovidesanalternativesolution forthisproblemviaenablingsingleantennawirelessdevicesina multi-userenvironmenttosharetheirantennasandgenerateavirtualmulti-antennatransmitterinordertoachievespatialdiversity. Thebroadcastandmulti-castnatureofthewirelesschannelisexploi
edincooperativecommunications.Thewirelessdeviceswhich'overhear'thetransmissionbetweentwointendedentitiescanforwardtheoverheardinformationandprovideanotherindependentlyfadedversionoftheinformationatthereceiver.Thus,eachdeviceinthenetworkissupposedtotransmititsowninformationaswell ascooperateindeliveringtheinformationoriginatingfromother devices.

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II. OBJECTIVE

Our main objective in this project is to study various existing schemes for resource allocationin cooperative communications and to develop novel approaches for the same.There are two fundamental paradigms that fall under the rubric of resource allocation -centralized and decentralized. The criterion for optimality we have selected is maximizationof sum throughput. We intend to develop a holistic framework to address both theseapproaches, with the aim of maximizing the sum throughput in a multiuser cooperativewireless network.

III. SYSTEM MODEL

We have considered a wireless ad-hoc network with Ns source-destination pairs, and Nrpotential candidates for relaying. Each source-destination pair has its own dedicatedchannel. Every candidate relay also operates at a different frequency band. If a relay nodeis cooperating with a given user, it overhears the source information and communicatesit to the receiver. Simultaneously, the source also communicates with the destinationthrough its dedicated channel. The destination, by virtue of receiving data from multiplechannels, applies maximum ratio combining (MRC) technique. Fig.3 represents thediagrammatic system model. In this scheme –

- hsr is the channel gain between the source and the relay
- hsd is the channel gain between the source and the destination –
- hrd is the channel gain between the relay and the destination

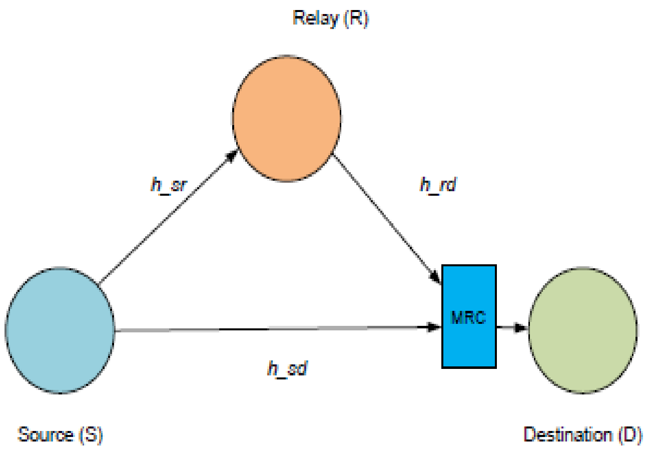

Fig 2 System Model

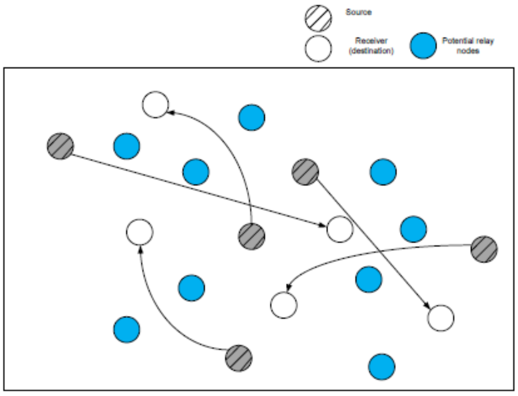

Fig 1 Typical Ad hoc network

IV. CENTRALIZED SCHEME

There has been much research on selecting an optimal relay node from a set of candidate nodes for a single source-destination pair. In a wireless ad hoc network, there are multiple source-destination pairs competing for the same pool of relays. Our focus istherefore, to develop a criterion to perform an optimal relay assignment for all users in anetwork from amongst a set of available relays. We will consider assignments that willmaximize the sum throughput of the network, while assigning at most one relay to asource-destination pair. A centralized scheme assumes complete information about allparticipants in the network. In our case, this translates to channel state information andSNR for all participating links, thereby enabling us to compute the requisite link capacities.In [1] Shi et al. have developed an efficient centralized node relay assignmentscheme that maximizes the minimum capacity over all possible assignments. Wehave studied and understood their approach to develop or own model for analysis.Wehave also simulated the algorithm proposed by themWe shall now proceed to develop a centralized relay assignment algorithm to achievesum rate maximization in the given network setting.

4.1 Problem Statement

We are given Ns source-destination pairs and Nr relays. We are given the capacity Ciφ for the directchannel between the source and destination, as well as the capacities Cij between the ith sourcedestinationcommunicating through the jth relay channel, for all j and i.Our aim is to assign each source-destination pair to at most one unique relay, such that this assignmentmaximizes the sum throughput of the network. In other words, there exists no other assignmentwhich can have greater sum throughput.

4.1.1 A Computationally Inefficient Solution

Given all the link throughput values, we are required to come up with the optimal assignmentas stated in equation 4.5. A brute force solution to the above stated problemwould be to compute the sum rate for all possible assignments, and to select the one which maximizes the required sum metric. As can be easily seen, this problemhas a running time that is exponential in the input size. More specifically it will take$O((Nr + Ns)(Nr + Ns - 1). \ . \ (Nr))$, which is computationally intractable.Therefore, there is a need to develop an efficient solution to the above problemwhich is computationally efficient (polynomial running time).

4.2 Solution

We have formulated a graph theoretic solution to the above problem based on networkflows. We model the given problem as a weighted bipartite graph matching problem.Graph matching problems are well studied in algorithms literature. Bipartite Matchinghas been discussed in [4]. We use the augmenting path approach to generate anoptimal assignment. The problem model, along with the algorithm, proof of correctnessand complexity analysis are detailed herewith.

4.2.1 Graph Construction

Let G be a bipartite graph with vertex set V = X U Y, where X,Y are disjoint sets.

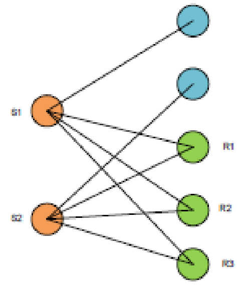

Figure 3: Example Graph Construction

Each vertex in X represents a unique source-destination pair |X| = Ns

Each vertex inmathcalY represents a unique relay or a direct channel between some source-destinationpair. |Y| = Nr+ Ns.

We construct the edge set Ɛas follows -

For every node i Є X there exists an edge eij between i Є X and j Є Y, if itis possible for the said source-destination pair to use the jth channel. Each such edge eij will have an associated non-negative real number cij.

Note: The Ns direct channels represented by nodes in Y will have one edge each corresponding totheir source-destination. The relays will have edges corresponding to multiple nodes in X.

The **Fig.5** gives an example construction of such a bipartite graph for Ns = 2, Nr = 3.

4.2.2Definitions

4.2.2.1 Bipartite Graph

A bipartite graph G can be partitioned into two disjoint vertex sets V = XUY, such that every edge e Є Ɛ has one end in X and the other in Y.

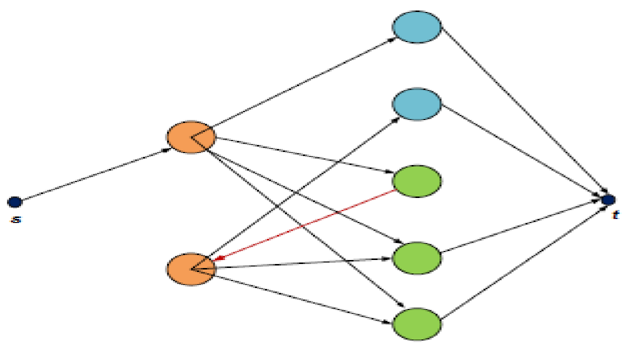

Figure 4: Residual Graph for Matching, |M| = 1

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4.2.2.2 Matching

A matching M in G is a subset of edges M⊆ℇsuch that each vertex appears in atmost one edge in M.

- The size of a matching is |M|
- The cost of a matching is $C_M = \sum e_{ij}\, è^{M} C^{ij}$

In our construction, M, such that |M|= Ns is the minimum cost perfect matching if

$C_M \leq C_M$; ∀M : |M| = Ns

4.2.2.3 Residual Graph

Let M be a matching. We add two new nodes s and t to the graph. We add edges(s, x) for all nodes x €X that are unmatched and edges (y, t) for all nodes y €Ythat are unmatched. An edge e = (x, y) is directed from x to y if e /€ M, and fromy to x if e € M.For all edges oriented from y to x, we replace the edge weight cxy with the negativevalue -cxy. All edges of the form (s, x) and (y, t) are assigned weight 0.The weighted, directed, bipartite graph so obtained for a given matching M isreferred to as the residual graph GM.

4.2.2.4 Augmenting Path

In the residual graph GM, let P be a directed path from s to t. If such a path exists, thenwe can construct a matching M', s.t. |M'| =|M| + 1. This can be achieved in thefollowing manner-

- if edge e in path P is directed from X to Y, then it is added to M
- if edge e in path P is directed from Y to X, then it is deleted from M

We call P, the augmenting path and use it to augment the matching M

4.2.3 Algorithm

We now present the optimal node relay assignment algorithm to maximize sum capacity.

Main Algorithm

Ns = number of source-destination pairs
Nr = number of relay channels
Construct Graph G
S = max(capacity(I,ℇj)) over all possible e(i; j) € **ℇ**
for every edge eij€**ℇ**, cij S □ capacity(i; j)
m = 0
M = Ø _
while m≠ Ns do
construct GM, the residual graph for matching M
compute the shortest path P from s to t in GM
call Augment(P,M,GM)
m = m + 1
end while
M is the minimum cost perfect matching of size Ns
e(x; y) € M assign xth source destination pair to yth relay channel

Augment(Path P, Matching M, Graph GM)

for every edgee €P do
if e is directed fromX to Y inGM then

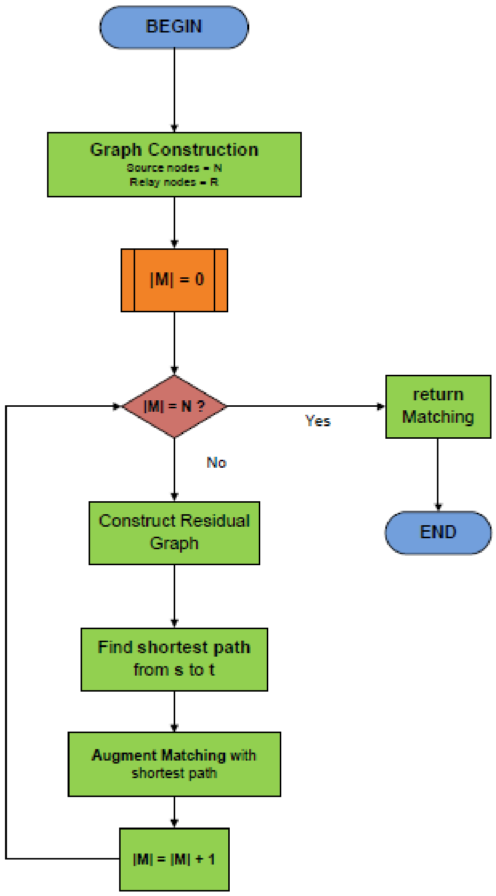

Figure 5: Description of Algorithm

e = (x; y)
Add e to M
else if e is directed fromY to X inGM then
e = (y; x)
Delete(x; y) fromM
else continue to next edge inP
end if
end if

4.2.4 Proof of Correctness

In the above algorithm, we are iteratively constructing a matching of size k + 1 from amatching of size k. We claim that the final matching of size Ns obtained, is theminimum cost matching.

Observation: Given a matching M and a path P from s to t in GM, let M0 bethe matching obtained by augmenting path P to M. Then |M'| = |M|+ 1 andCM'= CM + cost(P).Our aim therefore is to iteratively augment along paths of minimum cost to obtain amatching of size Ns.

A Negative Cycle is a collection of vertices forming a closed loop path suchthat the sum of edge weights < 0.

Lemma: Let M be a matching of size Ns. If there exists a negative cost cycleC in GM, then M is not minimum cost.

Proof: Note that s and t cannot be part of a cycle in GM, because there are no edgesemerging from s or t. If we were to use the edges of cycle C to augment the matchingM, we will get another matching M0 of size Ns. However, CM'= CM + cost(C) where cost(C) < 0. Thus, M is not of minimum cost.

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Lemma: Let M be a matching of size Ns. If there are no negative cost directedcycles in GM, then M is a minimum cost perfect matching.

Proof: Let M' be a matching of size Ns of smaller cost than M. Consider the set ofedges = M 4 M0. This edge set corresponds to a set of vertex disjoint directedcycles in GM. The cost of this set is CM'- CM < 0. Thus, it must be that at leastone of the cycles has negative cost.

With the above result, it is clear that we want to generate matchings of larger andlarger sizes while ensuring that in no iteration do we have a negative cycle. This isthe motivation behind choosing the smallest weight path from s to t as our augmentingpath. When we terminate with a matching of size Ns in the above algorithm, it isthe one that has minimum cost) Maximum Sum throughput.

Example 5.1: We presented the algorithm with the throughput values given inTable 5.1 (for a multiuser network with Ns = 5 and Nr = 4).

For the above data, our algorithm presented us with the optimal assignment tomaximize sum throughput. The returned assignment has been indicated in the table itself.

Source-Destination	R1	R2	R3	R4	ϕ
1	20	25	28	**30**	8
2	43	**63**	45	31	29
3	39	41	34	35	**14**
4	37	41	**56**	44	33
5	**59**	60	39	37	23

Table1. 1: Throughput matrix of Example 3

The total sum throughput in the optimal assignment = 222

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