Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
September 2008, 15(3): 47–50
The Journal of China Universities of Posts and Telecommunications
www.buptjournal.cn/xben

Partner selection strategies in cooperative wireless networks with optimal power distribution

ZHANG Qian-qian, GAO Wei-dong, PENG Mu-gen, WANG Wen-bo

Wireless Signal Processing and Network Laboratory, Beijing University of Posts and Telecommunications, Beijing 100876, China

Abstract

There have been several results that illustrate the best performance that a network can get through cooperation of relay nodes. For practical purposes, not all nodes in the network should be involved at the same time in every transmission. Therefore, optimal partner selection protocols in cooperative wireless networks are believed to be the first important thing that should be paid attention to. This problem in our article is considered in the context of regenerative nodes and non-altruistic cooperation (no pure relay exists; all nodes have their own data to transmit). For each transmission, the protocol must provide the user (source node) a 'best partner' (relay node) to cooperate with (for network simplicity and less transmission signals here, assume that each user has only one cooperative node). A criterion is essentially needed when defining what a 'best partner' is; in this article, two factors, i.e,. the successful transmission probability and the transmission power, are considered. Three optimal partner selection strategies with different goals are proposed and analyzed respectively. The simulation results show that these are all supposed to be good tradeoffs between power consumption and transmission performance.

Keywords cooperative, outage probability, power distribution, partner selection

1 Introduction

User cooperation has been proposed and well analyzed in recent years. It enables several nodes with single antenna in a specific area to form a virtual antenna array [1, 2], which provide spatial diversity in the sense of virtual combination. A novel partner selection strategy in cooperative wireless networks is proposed in Ref. [3], to find distributed approaches that achieve network-wide diversity gains such that each node can decode the message with high probability. In terms of the outage probability, this article explored a method selecting the group nodes in a way that best guarantees the transmission. In Ref. [4], optimum transmit power control in a wireless relay network is investigated with various cooperation protocols, assuming that the instantaneous channel gains are known only at the receiver side but the statistical models for these gains are available at the transmitter side. A utility function is defined in Ref. [5], which can be interpreted as the number of information bits received per Joule of energy expended. Similarly, using this utility function, Ref. [6] converts the node selection problem into generic assignment problems with different requirements; however, the cooperating node in one matching pair is not supposed to help the others except its matching node. We borrow the term 'utility' from these papers, but yet different from it, the dividend of the utility function is replaced by the successful transmission probability. With this changed definition, we can best balance the power distribution and the transmission quality.

In this article, first, through outage probability analysis between two cooperative nodes and a destination node, we will give the utility function, which has two variables, namely, the transmission power of source node and that of relay node, respectively. Then, we propose three optimal partner selection strategies, each with different emphases. The first one focuses on minimizing the total power consumed by two nodes, and is therefore called the minimum total-power utility (MTPU) strategy. The second one concentrates on minimizing the maximum power consumed by two nodes, which in a certain degree decreases each node's power offset and abstains some node level fairness, and therefore, this is called minimum max-power utility (MMPU) strategy. The last one emphasizes on the whole network power distribution evenness, and is called minimum average-power utility (MAPU) strategy.

The remaining sections of this article are organized as follows. Section 2 describes the system model and

---

Received date: 13-12-2007

Corresponding author: ZHANG Qian-qian, E-mail: zqq.bupt@gmail.com

characterization. Section 3 proposes and analyzes the three optimal partner selection strategies respectively. Section 4 provides the simulation results and Sect. 5 concludes the whole paper.

2 System model and characterization

Our network model consists of multiple nodes, namely, users, randomly distributed over a circular disk with an access point (AP) in the centre. The AP is the destination node, which has control of all the users and makes the decision about which user is to be which user's relay node. The user, which has data to transmit is a source node, and the user, which is ready to help another or already transmits another's data is called a relay node. Thus, the source node (SN), the relay node (RN), and the destination node (DN) compose the basic unit in our system model (see Fig. 1). In Fig. 1, SR, RD, and SD flows indicate source to relay, relay to destination, and source to destination, respectively.

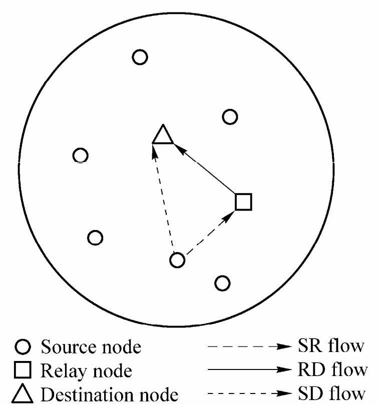
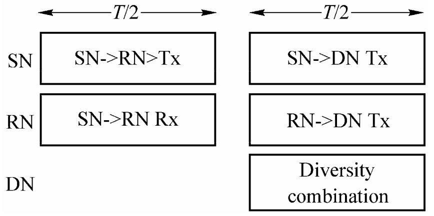


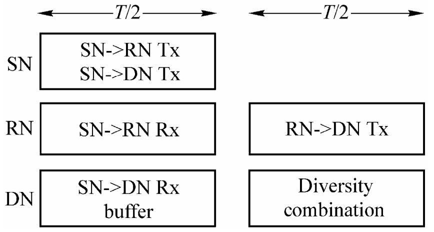
Fig. 1 A unit in a cooperative wireless network with a source node, a relay node, and a destination node

Generally, different from Ref. [6], here we allow non-reciprocal and non-altruistic cooperation (no pure relay exists, all nodes have their own data to transmit) without consideration of multi-hop transmission. Node *A* may give help to node *B*, then we simply decide that node *A* is the relay node of source node *B*, but this does not confine their roles in another transmission process. In other words, node *A* can also be a source node, or node *B* a relay node simultaneously, and the access point (destination node) sees all these users equally.

Each of the users is assigned an orthogonal multiple-access channel, i.e., in time, frequency, or spreading code. Figure 2 illustrates two example orthogonal transmission mechanisms for synchronous and asynchronous cooperation between source node and relay node. As we can see, in Fig. 2(a), source node transmits data to relay node in the first half frame, then in the next half frame, the source node and the relay node transmit data to the destination synchronously, so that the destination node receives and combines them at the same time; in Fig. 2(b), the source node transmits data to the relay node as well as the destination simultaneously in the first half frame, and the destination puts the first received data into buffer. Then, in the next half frame, the relay node retransmits its received data to the destination, which will finally be combined with the data in the buffer.



(a) Synchronous cooperation



(b) Asynchronous cooperation between source and relay node

Fig. 2 Example of orthogonal transmission mechanisms

The physical channel from node *i* to node *j* (both *i* and *j* can be source node, relay node, and destination node) has instantaneous signal-to-noise ratio (SNR)

$$r_{i,j} = \Gamma |h_{i,j}|^2 \tag{1}$$

where, $|h_{i,j}|$ is the Rayleigh-distributed fading magnitude with $E\{|h_{i,j}|^2\} = 1$. The term Γ represents the average SNR of the channel over fading

$$\Gamma = \Gamma_{\mathrm{T}} \Gamma' = \frac{P}{N_0} K S_{i,j} d_{i,j}^{-\beta} \tag{2}$$

where, $\Gamma_{\mathrm{T}} = P / N_0$, P is the transmit power, N_0 is the additive white Gaussian noise power at the receivers, K is the path loss for an arbitrary reference distance, $S_{i,j}$ is a log-normal shadowing component, with $10\log S_{i,j}$ having a mean of 0 dB and standard deviation σ_S (dB), $d_{i,j}$ is the distance between nodes *i* and *j* (normalized by the reference distance), and $\beta \geqslant 0$ is the path loss exponent. We consider quasistatic fading, such that the fading coefficients $\{h_{i,j}\}$ are constant for a given transmitted block, or code word, but are independent identicall distributed (i.i.d.) for different blocks. We assume that small scale fading between two nodes is not entirely dominated by path loss and shadowing, and the relay uses DF (decode and forward) transmission method, that is, the node, which is to cooperate, must decode the intended signal. The cooperation transmission is integrated with the characteristics of the media access control (MAC) layer, e.g., frequency division multiple access (FDMA), time division multiple access (TDMA), or code division multiple access (CDMA), such that a node is not transmitting and receiving at the same time. Detailed explanations can be found in Refs. [7, 8].

In Ref. [3], the outage probability of a transmission with cooperation is characterized and explained in detail. It is assumed that each node may give help to n other nodes, and the selection strategy guarantees diversity $n+1$ for all transmissions. With more nodes, the diversity can be fully achieved, but it indicates that in one transmission occurrence, $n+1$ nodes are evolved, the system complexity is considerably increased, and it is even more difficult for practical implementation. Therefore, in this article, we assume that there are two nodes in cooperation at large. Outage probability in Ref. [2] formulates under the premise that each node's transmit power is constant, and the effect that a different transmitting power distribution should achieve is not of concern in this article. Nevertheless, besides the outage probability for one transmission, the power consumed for each node (source node and relay node) is important resource for the users and the whole network, since less transmitting power indicates prolonged lifetime of the users and less interference for the whole network.

3 Partner selection strategies

The outage probability is the chance that the channel capacity

$$C(\gamma)=\log_2(1+\gamma) \tag{3}$$

cannot support the desired rate. For the case of Rayleigh fading, γ has an exponential pdf with parameter $1/\varGamma$, where, $\varGamma$ is the average SNR of the channel over fading. Thus, the outage probability results in the expression

$$\mathrm{Pr}_{\mathrm{OUT}}=\int_0^{2^R-1}\frac{1}{\varGamma}\exp\left(-\frac{\gamma}{\varGamma}\right)\mathrm{d}\gamma=1-\exp\left(-\frac{2^R-1}{\varGamma}\right) \tag{4}$$

where, R denotes the required rate in one given transmission. Suppose $\varGamma_{\mathrm{SR}}$, $\varGamma_{\mathrm{SD}}$, and $\varGamma_{\mathrm{RD}}$ are the average SNRs of SN to RN, SN to DN, and RN to DN, respectively, which are relevant to the distance between SN and RN, SN and DN, and RN and DN, and the power transmitted by SN and RN. Thus, similar to Eq. (4), we can give the outage probabilities for the two regions as shown in Fig. 3.

The outage probability expression of SN to RN is

$$\mathrm{Pr}_{\mathrm{SRout}}=\int_0^{2^R-1}\frac{1}{\varGamma_{\mathrm{SR}}}\exp\left(-\frac{\gamma_{\mathrm{SR}}}{\varGamma_{\mathrm{SR}}}\right)\mathrm{d}\gamma_{\mathrm{SR}}=1-\exp\left(-\frac{2^R-1}{\Gamma_{\mathrm{SR}}}\right)=$$
$$1-\exp\left(-\frac{2^R-1}{\Gamma_{T\mathrm{SR}}\varGamma'_{\mathrm{SR}}}\right) \tag{5}$$

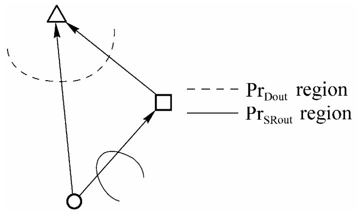


Fig. 3 The two regions in a unit given for calculations of outage probability in a cooperative wireless network

Linking SN to DN and RN to DN together composes a virtual link; hence the outage probability expression of SN, RN to DN is

$$\mathrm{Pr}_{\mathrm{Dout}}(d)=\int_F\int\frac{1}{\varGamma_{\mathrm{SD}}\varGamma_{\mathrm{RD}}}\exp\left(-\frac{\gamma_{\mathrm{SD}}}{\varGamma_{\mathrm{SD}}}-\frac{\gamma_{\mathrm{RD}}}{\varGamma_{\mathrm{RD}}}\right)\mathrm{d}\gamma_{\mathrm{SD}}\mathrm{d}\gamma_{\mathrm{RD}} \tag{6}$$

where, F is the set of channel conditions in $\mathrm{Pr}_{\mathrm{Dout}}$ region that do not support the required transmission rate. Once F is decided, then, Eq. (6) can be solved. If the cooperating node will only retransmit the decoded signal that has been correctly decoded, then, F can be expressed as

$$F\equiv\{1+\gamma_{\mathrm{SD}}+\gamma_{\mathrm{RD}}<2^{2R}\} \tag{7}$$

In this way, the successful probability for a given transmission can be educed from the above Eqs. (5)–(7)

$$\mathrm{Pr}_{\mathrm{SUC}}=(1-\mathrm{Pr}_{\mathrm{SRout}})(1-\mathrm{Pr}_{\mathrm{Dout}})+$$
$$\mathrm{Pr}_{\mathrm{SRout}}(1-\mathrm{Pr}_{\mathrm{OUT}}(\mathrm{SD}\,|\,\gamma_{\mathrm{SD}}\leqslant 2^{2R}-1)) \tag{8}$$

As long as both regions are satisfied with the capacity requirement, the transmission succeeds. Equation (8) is a function with variable parameters P_{S} and P_{R}, the transmit power of SN and RN, respectively. The successful probability for one transmission will increase with larger SNR, which indicates higher source power and relay power. However, power resource is important both on the user side and on the network side, and to always work on the highest power for SN and RN is unpractical and improvident as well. Therefore, we should contrive to find the balancing point between the successful probability and consumed power. With some rules to confine the two nodes' transmit power, our sole objective is to determine the cooperating RN, which can maximize the successful transmission probability, that is,

$$\mathrm{Pr}_{\mathrm{maxSUC}}=\arg\max_C\mathrm{Pr}_{\mathrm{SUC}} \tag{9}$$

C is the rule confining P_{S} and P_{R}. There can be three different rules, which are,

1) $\min(P_{\mathrm{S}}+P_{\mathrm{R}})$.
2) $\min\{\max(P_{\mathrm{S}},P_{\mathrm{R}})\}$.
3) $\min\sqrt{\left|(P'_{\mathrm{S}}+P_{\mathrm{S}}-\overline{P})(P'_{\mathrm{R}}+P_{\mathrm{R}}-\overline{P})\right|}$.

$\overline{P}$ is the average transmit power of SN and nodes that can detect the cooperating request messages sent by SN. P'_{S} and P'_{R} are the current transmit powers for the source and relay at a given time. We can see that this is a two objective optimization problem. Here, we define a utility function

$$U = \frac{P_{\mathrm{SUC}}^{\varepsilon}}{f(P_{\mathrm{S}}, P_{\mathrm{R}})} \tag{10}$$

The penalty factor of $\varepsilon \geqslant 1$ in the numerator guarantees high priority for the successful transmission probability. Therefore, the problem proposed above can be rewritten as follows:

$$U' = \arg\max_{P_{\mathrm{S}}, P_{\mathrm{R}}} U = \frac{P_{\mathrm{SUC}}^{\varepsilon}(P_{\mathrm{S}}, P_{\mathrm{R}})}{f(P_{\mathrm{S}}, P_{\mathrm{R}})} \tag{11}$$

This is the essence of this article, and with different rules defined by C in Eq. (9), three different strategies can be derived as follows:

1) MTPU strategy

$$f(P_{\mathrm{S}}, P_{\mathrm{R}}) = \min(P_{\mathrm{S}} + P_{\mathrm{R}}) \tag{12}$$

This one focuses on minimizing the total power consumed by two nodes, and is therefore called the MTPU strategy. This strategy does not consider the power parity between the two nodes, therefore, in some cases, there may be considerable difference in power consumption by them.

2) MMPU strategy

$$f(P_{\mathrm{S}}, P_{\mathrm{R}}) = \min\{\max(P_{\mathrm{S}}, P_{\mathrm{R}})\} \tag{13}$$

The second one focuses on minimizing the maximum power consumed by the two nodes, which in a certain degree, decreases each node's power offset and abstains some node level fairness; therefore, this is called the MMPU strategy.

3) MAPU strategy

$$f(P_{\mathrm{S}}, P_{\mathrm{R}}) = \min\sqrt{\left|(P_{\mathrm{S}}' + P_{\mathrm{S}} - \overline{P})(P_{\mathrm{R}}' + P_{\mathrm{R}} - \overline{P})\right|} \tag{14}$$

The last one targets on the minimization of the two nodes' offset, and hence guarantees the whole network power distribution evenness, and is called the MAPU strategy.

4 Simulation results

In this section, we evaluate the performances of our three partner selection strategies via computer simulations. Here, we assume that n nodes are randomly distributed around SBN and DN ranging from 2 to 10, and the position of DN and SN are predetermined (this is true since in a short time the position of SN can be seen as immovable). Path loss and quasistatic Rayleigh fading are considered.

All simulations use $R = 1/3$, $\varepsilon = 2$, and $\beta = 4$, and the Monte Carlo times is set at 50 (note that the simulation results are only used as representative examples to demonstrate the system optimization with different strategies).

Figure 4 compares the transmission successful probability under different partner selection strategies. MSNR represents the Maximum SNR in each transmission for source and relay node, therefore, it has high successful probability and relatively small changes in spite of the increase of the nodes. The successful probability for MTPU and MMPU increases with node number, because when the nodes increase, there are more chances to select a better relay node out of them. However, the condition reverses for the MAPU case, since it is related to the current and average transmit power; therefore, when the nodes increase, it is difficult to balance the transmission power, and the successful probability drops.

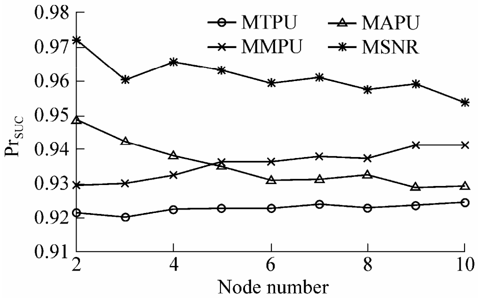


Fig. 4 Transmission successful probability under different strategies with the increasing nodes

Figure 5 compares the transmission power of source node plus relay node and Fig. 6 compares the maximum transmission power between them under different strategies.

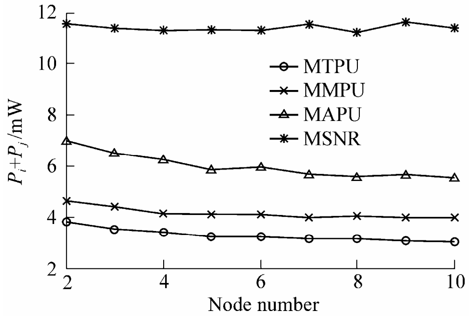


Fig. 5 Transmission power of source node plus relay node under different strategies with the increasing nodes

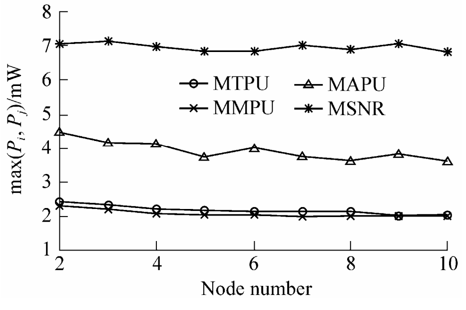


Fig. 6 The maximum transmission power between source node and relay node under different strategies with the increasing nodes

In each of them, the MSNR strategy remains far above others, because higher SNR results in higher power. The

To p. 58

traceback. Computer Communication Review, 2000, 30(4): 295–306

4. Dawn X S, Perrig A. Advanced and authenticated marking schemes for IP traceback. Proceedings of the 20th Annual Joint Conference of the IEEE Computer and Communications Societies, Apr 22–26 2001, Anchorage, AK, USA. Piscataway, NJ, USA: IEEE, 2001: 878–886
5. Yaar A, Perriq A, Sonq D. Pi: a path identification mechanism to defend against DDoS attacks. Proceedings of Symposium on Security and Privacy, May 11–14, 2003, Berkeley, CA, USA. Piscataway, NJ, USA: IEEE. 2003: 93–107
6. Park K, Lee H. On the effectiveness of probabilistic packet marking for IP traceback under denial of service attack. Proceedings of the 20th Annual Joint Conference of the IEEE Computer and Communications Societies, Apr 22–26, 2001, Anchorage, AK, USA. Piscataway, NJ, USA: IEEE, 2001: 338–3347
7. Tchakountio F, Kent S T, Strayer W T. Hash-based IP traceback. Proceedings of Conference on Applications, Technologies, Architectures, and Protocol for Computer Communication (SIGCOMM'01), Aug 27–31, 2001. San Diego, CA, USA. New York, NY, USA: ACM, 2001: 3–14
8. Bellovin S, Leech M, Taylor T. Internet draft. ICMP traceback messages. [2007-02-01]. http://tools.ietf.org/html/draft-ietf-itrace-04
9. Chang R K C. Defending against flooding-based distributed denial-of-service attacks: a tutorial. IEEE Communications Magazine, 2002, 40(10): 42–51

From p. 50

remaining curves in them either drop or stay along with the increase of nodes, since more nodes indicates more choices.

Figure 7 compares the power offset that each transmission suffers for SN and RN from the average power of surrounding nodes. The definition of offset is

$$\phi_{\text{offset}} = \frac{P_{\text{current}} + P_{\text{to\_be\_used}}}{P_{\text{average}}} \qquad (15)$$

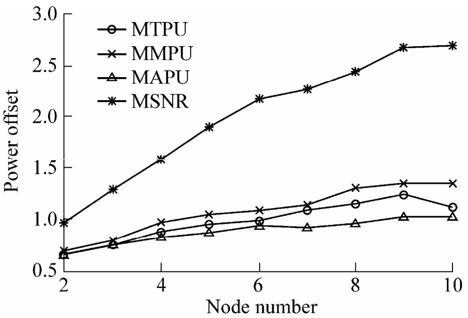


Fig. 7 The power offset for SN and RN under different partner selection strategies with the increasing nodes

The total offset equals $\phi_{\text{offset\_S}} + \phi_{\text{offset\_R}}$, which is the summation of the source and the relay offsets. We can see that for all four strategies, the power offset increases when the nodes increase, while the MSNR strategy remains the highest, and the MAPU strategy has more plane trends than the others, which adequately fulfill its original intention.

5 Conclusions

In this study, we consider partner selection strategies for cooperative wireless communications. Our solitary goal is to determine the best way to balance the power distribution and transmission performance. Three different partner selection strategies are proposed, and as the simulation results show, all are supposed to be good tradeoffs between power consumption and transmission performance with different goals.

Acknowledgements

This work is supported by the Hi-Tech Research and Development Program of China (2006AA01Z257).

References

1. Mischa D. Virtual antenna arrays. London, UK: King's College London, 2003
2. Wang Q H, Zhao B H. Protocol for the application of cooperative MIMO based on clustering in sparse wireless sensor networks. Journal of China Universities of Posts and Telecommunications, 2007, 14(2): 51–57
3. Aria N, Todd E H. Grouping and partner selection in cooperative wireless networks. IEEE Journal on Selected Areas in Communications, 2007, 25(2): 369–378
4. Ramesh A, Pamela C C, Laurence B M. Statistical channel knowledge-based optimum power allocation for Relaying protocols in the high SNR regime. IEEE Journal on Selected Areas in Communications, 2007, 25(2): 292–305
5. Goodman D J, Mandayam N B. Power control for wireless data. IEEE Personal Communications, 2000, 7(2): 48–54
6. Chen Y, Cheng P, Qiu P L, et al. Optimal partner selection strategies in wireless cooperative networks with fixed and variable transmit power. Proceedings of Wireless Communications and Networking Conference, (WCNC'2007): Mar 11–15, 2007, Kowloon, China. New York, NY, USA: IEEE, 2007: 4080–4084
7. Laneman J N, Tse D N C, Wornell G W. Cooperative diversity in wireless networks: efficient protocols and outage behavior. IEEE Transactions on Information Theory, 2004, 50(12): 3062–3080
8. Todd E H, Aria N. Diversity through coded cooperation. IEEE Transactions on Wireless Communications, 2006, 5(2): 283–289