Survey of Resource Allocation Techniques in Cooperative Communication

Usha Padma* H.V.Kumaraswamy* and S.Ravi Shankar**
*Department of Telecommunication Engineering, R.V.College of Engineering, Bengaluru
kamakshimb@rvce.edu.in, kumaraswamyhv@rvce.edu.in
**Electronics and Communication engineering, R.V.College of Engineering, Bengaluru
ravishankars@rvce.edu.in

Abstract: One of the solutions for edge users and low power devices in wireless networks is Cooperative communication(CC) and is expected to be an emerging technology for efficient use of resources in future. The basic unit in CC is a three terminal network where the relay cooperate with the source by sharing its resources, to make successful communication between source and destination. There is a need to allocate resources efficiently in CC to overcome the challenges and demands of next generation wireless networks. A survey of different methods of allocating resources in CC is discussed. We provide an overview of objectives, protocols, network configuration , decision types and literature of resource allocation in CC.

Keywords: Resource allocation, Cooperative communication, Decision types, Network configuration, Objectives.

Introduction

There are high increase of mobile users in today's world where there is a very high demand on the data transmission rate and channel bandwidth. The wireless communication has to overcome challenges such as fading, Doppler shift etc. The promising multiple input multiple output (MIMO) technology has served this purpose, but there is extra use of hardware i.e., antenna and usage of power. To overcome these impairments that are found in wireless, "cooperative communication" or diversity techniques have been proposed. Co-operative communication uses the co-operative techniques where devices co-operate to transmit the signals over the air which exploits distributed form of spatial diversity that mitigates the negative effects of signal fading, interference etc. Direct communication or point to point communication is the one in which communication exists between sources(S) and destination(D) may be base station or mobile. For co-operative communication, user co-operation is made possible whenever there is at least one additional node. Co-operative communication is regarded as virtual MIMO system, which can efficiently mitigate the fading multipath channel. It creates an independent path between source and destination i.e., it acts as an auxiliary channel to the existing point to point communication.

CC protocols can be categorized into fixed relaying(FR) and adaptive relaying(AR) schemes. In FR schemes the available channel resource is divided among source and relay. In case of adaptive, comprising selective and incremental relaying are allowed.

Allocation of Resources in Cooperative Communication

This section briefs about the types of resources that can be allocated in CC. Types of the resources include : Power, Relay, User scheduling, Routing, Quality of service, Delay, Time slot, Bandwidth and Subcarrier.

Power

In any wireless communication system, maximum power is consumed by the RF devices (Communication unit). Hence there is requirement to allocate power efficiently to source and relay. Maximum researches have contributed towards allocation of this element in CC.In [2],[5],[7], [9], [12],[13],[14],[22] , and [25], authors investigated different optimal power allocation(PA) methods. Adaptive PA method was investigated by [3] under power constraint, according to fading state information and [6] subject to the constraint of available energy. An incremental power assignment algorithm, based on the knowledge of the average channel power attenuation and combining method at the receiving node was proposed in [8].Game theoretic approach is applied on source and relays, to allocate power in [10]and [16]. In [10], source nodes buy power from relay nodes. Here relays attract source nodes by setting proper prices. In [16], two source nodes cooperate each other by relaying each other's data. Authors designed power auction scheme to allocate power to the relay nodes and the same was extended in [20], where a node was made to act as both seller as well as buyer and the price of the auctioneer was announced independently. Contract theory and auction mechanisms were combined so as to provide maximum possible utility for source and relay nodes. Primal–dual decomposition technique was proposed to allocate power in a OFDMA CC network. Power was allocated using Two level dual decomposition and subgradient(TLDDS) method in a multiuser cooperative OFDMA uplink(UL) system to maximize the throughput[32].Power was allocated using gradient power allocation scheme in a multiuser OFDM system, maximizing the throughput of the network in[30]. Work in [30] was extended for allocation of power in UL OFDMA system for multiplexed relays. Authors developed a new algorithm based on Water filling algorithm(WFA), to allocate power in a multiuser CC network[24]. WFA was also used in LTE advanced CC systems to allocate power while satisfying the users QOS[31].In[28], authors investigated particle swarm optimization(PSO) as a solution for power allocation in a multiple source multiple relay AF and CC system. An instantaneous CSI based PA (ICPA) was scheme was proposed, where power was adjusted dynamically as a function of instantaneous fading states[34]. This scheme required local CSI at each node.

Relay

Relay benefits CCN by increasing the transmission rate and reducing the total power consumed for transmission. Multiple relays further benefits performance of CCN by cooperating to transmit the source data. A distributed scheme was proposed [4] to find one finest path from S to D amongst all available relays where Relays are not required to communicate among them, and does not require any prior knowledge about the network topology. Best relay selection was based on the instantaneous measurements of unguided channel and reciprocity. This method simplified space time coding as one best relay was used to transmit in the second phase. Authors in [11] proposed a method to select the suitable relay considering the one with highest mutual information to carry the source data to destination. The relay which consumes least power was selected to cooperate with the source in [14].Linear marking being a part of polynomial time algorithm was used in [15], where multiple Source destination pairs computed for a common pool of relays in the network. A node that relays data on the optimal subcarrier is selected to transmit the source node data. Optimal relay assignment method was used in [17],[18], [19], [23] and [25] to select suitable relays based on certain parameters. TLDDS method was used to select a suitable relay in a multiuser cooperative OFDMA UL system, so that throughput is maximized [26].Fine-grained resource allocation Scheme was used to select a best relay among multiple relays in a device to device communication of cellular networks[27]. Authors of [28] designed and developed a PSO algorithm to select a suitable relay in CC. A MAC was designed in which the channel access probability of a node depended on the local utility function, which in turn helped to choose a suitable relay based on its congestion window size. A new MAC protocol, CoCogMAC was designed to assign a suitable relay node to the source in order to maximize the utility for the link [29]. A best relay was selected to maximize the utility of the network using cross layer scheme and dual decomposition method in [9]. Relay selection is performed based on the mutual information method and max-min selection technique in [10].Game theory concepts were used in [21] and [35] to solve the problem of resource assignment. SNR and power auction methods were used to allocate relays to the source in a distributed manner.

User Scheduling

It is used to select best users at particular time slot , which helps for the attainment of maximum throughput. As the number of users increases, the complexity of extensive search for user scheduling also increases exponentially. This is an active research area in CC. Very few researchers have contributed in allocating this particular resource in CC[27] [29].

Routing

Majority of the researchers have concentrated on single or two hop scenario. But for ad hoc networks, researchers are realizing the significance and capability of multihop CC. It is necessary to address and find solution , in order to gain the profits of multihop transmission. Especially efficient routing methods have to be incorporated in ad hoc CC.

Differential backlog-aware routing was discussed in[34], where the next hop is selected based on the size of the queue length and each intermediate node. Information about the queue size was feedback from the intermediate nodes through a MAC protocol called CoCogMAC.

Bandwidth

Initially Optimal Bandwidth allocation(BA) scheme was proposed by splitting the available bandwidth among the users. In [21] and [28], Optimal BA was based on the throughput. In [6], [35] ,[9] and [13] an adaptive BA scheme was proposed.

Quality of Service

It includes throughput, outage, blocking probabilities, latency and rate. The chief goal of QOS in CC is to assure minimum latency, rate and errors. This parameter has always been used to measure the performance of the entire network. Very few have considered this as one of the resources that could be allocated in CC.

Delay

It is a very essential metric for any real time application in wireless network. In CC delay is still a uncultivated research area.

Subcarrier

Pairing and subcarrier allocation is a very important role in CC where OFDM and OFDMA are employed in physical layer. With efficient exploitation of subcarriers, it is possible to improve the throughput of CC. [24],[26] and [30] have contributed towards allocation of subcarriers in OFDM and OFDMA systems.

Table1.Decision types

References	Decision	Channel State Information
[2],[9],[11]-[12],[17],[24],[26], [27],[30],[31], [33],[34],[36]	Centralized	Known
[3]	Centralized	Known, Mixed
[4],[10], [13],[20], [22],[32],[35]	Distributed	Unknown
[5]		Known
[7],[16],[18],[19][28], [29]	Distributed	Known
[14]	Centralized	Unknown

Cooperative Communication Protocols

Three cooperative protocols that are commonly used in research are amplify and forward (AF),decode and forward(DF) and compress and forward(CF). In DF , relay receives signal from S and this received signal will be decoded and again encoded, and then it will be retransmitted to the D. In AF, the relay scales the received signal and transmits the scaled version of the signal to the D. In CF, the received signal will be compressed and then retransmitted to the D. Authors have considered AF protocol in [10],[14],[20],[22],[23],[28] and [36]. DF protocol has been used by [3],[6],[8],[13],[17], [19], [24], [25], [26], [30], [31] and [33]. Some researchers have considered both and they are [9],[12],[15],[18],[27],[29] and [32]. Selection-AF[7], Demodulate and forward[11] and Network coded cooperation[34] are some of the others protocols which are considered. Decision types and CSI considered by the authors are listed in Table 1.

Network Configuration

Network configuration provides information about number of receivers, transmitters and relays that are used in any CC network. For centralized CC networks, single transmitters are considered in [2]-[7], [9], [11], [14], [17], [22], [30],[31], [36] and Multiple transmitters are considered in [15],[16],[18,[23]-[29], [32]-[35]. Transmitter acts as controller of network in centralized CC network. Number of relays and receivers play important role in designing a CC network.System performance can be improved in CC network by employing more than one relay, where use of many relays provides the flexibility of selecting the best path between S-R(s) and R-D(s). This in turn leads to increased complexity of the network. Diversity order and capacity of channel increases with the number of relays employed. CC networks with single relay are considered in [2]-[3],[5],[6],[11],[12] and [31] where as multiple relays are considered in [4],[7],[9],[13]-[30] and [32]-[36].Single receiver is considered in [2]-[14],[16],[17], [22],[24],[28] , [30]-[36] and multiple receivers are considered in [15],[18]-[21],[23],[25]-[27],[29].

Classification of Cooperative Communication Objectives

The objectives are classified into four categories and it includes fairness, minimization, maximization and performance analysis. Table 2 shows the objectives considered by different authors.

Fairness

In CC, fairness is necessary to make balanced exploitation of the radio resources . Network admin is required to maximize the most awful throughput of the user in max-min fairness. In proportion to the user demand, radio resources need to be allocated in rate proportional fairness.

Minimization

There is a requirement to minimize certain parameters of network in some situations of CC. Most valuable resources in CC are bandwidth and power. Hence it is necessary to allocate these resources in a manner that they are least consumed. However, Delay should be minimized in real time scenarios.

Table 2. Objectives

References	Minimization	Fairness	Maximization	Analysis
[2],[4], [7]				Outage probability
[3]				Channel capacity
[8],[11].		Max-Min		
[9],[10],[16],[32]			Utility	
[12]	Delay		Sum rate	
[13],[17],[20],[22],[26],[28],[29],[30],[36].			Sum rate	
[14],[25],[33],[34]	Power			
[15]			Capacity	
[19],[31]	Power		Sum rate	
[18]			Data rate	
[23],[27]				Capacity
[35]			Energy efficiency	

Maximization

Sumrate, receiver SNR, capacity utility of the network are to be maximized in CC. The disadvantage of maximizing SNR is, the total throughput of the network cannot be found by SNR. For efficient allocation of radio resources , utility of the network optimization is a prevailing tool.

Performance Analysis

Usually outage minimization and bit error rate are considered as metrics to measure performance of the network in CC.

Future Research Directions

The aspects of allocating resources in CC are discussed in this survey. Still there are many issues which needs to be addressed. Some important issues that are to be addressed are:

Use of Network Coded Cooperation (NCC)

There are very few papers available in the literature. NCC basically deals with the use of coding techniques. In NCC the relay attempts to transmit its own data while cooperating with one of the source data. Here relay transmits both data (relay originated data and source data) in the same time slot. Combining two data at the relay and recovering these data at the destination is a challenging issue in NCC.

Multihop relaying in CC

Though some papers are available for multihop relaying in CC, some issues still need more study and attention. Transferring data in bidirectional multihop CC networks by optimally allocating power or other resources is still a open issue. There is a need to minimize the number of relays while maintaining the QOS of the users. Impact of imperfect CSI can also be considered for allocating resources in a distributed and centralized CC network.

Green Communication(GC)

Researchers have focussed on functionality and measurement of the performance in CC. But devices that are driven by the batteries also need to be considered. GC is an exercise of choosing energy efficient communication by minimizing the use of resources in all possible branches of communication. Optimal PA techniques in CC to improve energy efficiency while maintaining the QOS is an open issue to be addressed. User's cooperation induce overheads in CC and there is a need to reduce the power consumed by these overheads.

Conclusion

A research on allocation of resources in CC is challenging and quite elaborative. As the number of users are growing day by day, there is scarcity of resources in wireless networks. To meet this challenge it is necessary to utilize resources in a efficient manner. We explored the components for allocation of resources in CC and also provided broad literature review on network configuration, types of protocols, Objectives to be attained , decision types and future research directions in CC.

References

[1] Ankit jai shankar pal, "Performance Characteristics Evaluation for Cooperative Communication", Department of Electrical Engineering National Institute of Technology,Rourkela Rourkela-769008, Odisha, India 2011-2013.

[2] M. O. Hasna, M.S. Alouini, "Optimal Power Allocation for Relayed Transmissions Over Rayleigh-Fading Channels", *IEEE* Transactions On Wireless Communications, VOL. 3, NO. 6, Nov 2004, pp.1999-2004.

[3] Z. Qi, Z. Jingmei, S. Chunju, W. Y, Zhang Ping, H. Rong, "Power Allocation for Regenerative Relay Channel with Rayleigh Fading", Proceedings of IEEE 59th Vehicular Technology Conference, 2004. VTC 2004-Spring.

[4] Bletsas, A. Lippman , David P. Reed, "A Simple Distributed Method for Relay Selection in Cooperative Diversity Wireless Networks, based on Reciprocity and Channel Measurements", Proceedings of IEEE 61st Vehicular Technology Conference, May 2005.

[5] A. Høst-Madsen, and J. Zhang, "Capacity Bounds and Power Allocation for Wireless Relay Channels", IEEE Transactions On Information Theory, Vol. 51, No. 6, June 2005

[6] Yi Zhao, R. Adve and T. J. Lim, "Improving Amplify-and-Forward Relay Networks: Optimal Power Allocation versus Selection", ISIT 2006, Seattle, USA, July 9 14, 2006.

[7] K. Lee and A. Yener, "Iterative Power Allocation Algorithms for Amplify/Estimate/Compress-and-Forward Multi-Band Relay Channels", 40th Annual conference on Information Sciences and Systems, March 2006, pp.1318-1323.

[8] S. Savazzi, U. Spagnolini, "Energy Aware Power Allocation Strategies for Multihop-Cooperative Transmission Schemes", IEEE Journal On Selected Areas In Communications, Vol. 25, NO. 2, February 2007, pp.318-327.

[9] T. Chiu-Yam Ng and W. Yu, "Joint Optimization of Relay Strategies and Resource Allocations in Cooperative Cellular Networks", IEEE Journal On Selected Areas In Communications, Vol. 25, NO. 2, February 2007,pp.328-339.

[10] B. Wang, Z. Han, and K. J. Ray Liu, "Distributed Relay Selection and Power Control for Multiuser Cooperative Communication Networks Using Buyer/Seller Game", 26th IEEE International Conference on Computer Communications **,** IEEE INFOCOM 2007, 6-12 May 2007.

[11] Josephine P. K. Chu, R. S. Adve, and A. W. Eckford, "Relay Selection for Low-Complexity Coded Cooperation",Global Telecommunications Conference, 2007, Globecom'07,26 Dec 2007, pp.3932-3936

[12] J. Tang, Xi Zhang, "Cross-Layer Resource Allocation Over Wireless Relay Networks for Quality of Service Provisioning", IEEE Journal On Selected Areas In communications, Vol. 25, NO. 4, May 2007, pp.645-656.

[13] H. Li, Hui Yu, H. Luo, Jia Guo, Chisheng Li, "Dynamic Subchannel and Power Allocation in OFDMA-Based DF Cooperative Relay Networks", Global Telecommunications Conference, 2008, Globecom'08,8 December 2008.

[14] H. Goudarzi, H. Goudarzi, "Optimal Partner Selection and Power Allocation for Amplify and Forward Cooperative Diversity", IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, 2008, 8th December 2008.

[15] Yi Shi, S. Sharma, Y. Thomas Hou, S. Kompella, "Optimal Relay Assignment for Cooperative Communications", Proceedings of the 9th ACM International Symposium on Mobile Ad hoc Networking and Computing, pp.3-12.

[16] M. Janzamin, M.R. Pakravan, Hanie Sedghi, "A Game-Theoretic Approach for Power Allocation in Bidirectional Cooperative Communication",IEEE Wireless Communications and Networking Conference,2010, 18-21 April 2010.

[17] E. Beres ,R. Adve, "Optimal Relay-Subset Selection and Time-Allocation in Decode-and-Forward Cooperative Networks", IEEE Transactions on Wireless Communications, vol.9, no. 7, pp. 2145-2155.

[18] S. Sharma, Yi Shi, Y. T. Hou, S. Kompella, "An Optimal Algorithm for Relay Node Assignment in Cooperative Ad Hoc Networks", IEEE/ACM Transactions On Networking, Vol. 19, No. 3, June 2011, pp.879-892.

[19] Y. Li, P.Wang, D. Niyato, W. Zhuang, "A Dynamic Relay Selection Scheme for Mobile Users in Wireless Relay Networks", Mini-Conference at IEEE INFOCOM 2011.

[20] Y. Liu, Tao, and J. Huang, "An Auction Approach to Distributed Power Allocation for Multiuser Cooperative Networks", IEEE Transactions On Wireless Communications, 2012.

[21] H. Xu, Y.Yun Chen, Q. Liu, S. Yang, X. Zhou, "Self-Optimization of Resource Allocation in Cooperative Relay Networks", 21st Annual Wireless and Optical Communications Conference(WOCC),April 19-21, Kaohsiung, Taiwan, 2012, pp.89-92.

[22] J. Liu, N. B. Shroff, H. D. Sherali, "Optimal Power Allocation in Multi-Relay MIMO Cooperative Networks: Theory and Algorithms", IEEE Journal On Selected Areas In Communications, Vol. 30, No. 2, February 2012, pp. 331-340.

[23] K. Xie,J.N. Cao, J. Wen, "Optimal Relay Assignment and Power Allocation for Cooperative Communications", Journal Of Computer Science And Technology 28(2): 343{356 Mar. 2013. DOI 10.1007/s11390-013-1335-3.

[24] B. Chen, Y. Li, Y. Wu, X. Liu, T. Zou, " Power-Minimizing Resource Allocation in Multiuser Cooperative Relay Communications", Journal of Computer Science and Communications, Vol.5, No.3C, September 2013.

[25] K. Xie , J. Cao , X. Wang , J. Wen, "Optimal Resource Allocation for Reliable and Energy Efficient Cooperative Communications",

[26] M. S. Alam, J. W. Mark, X. Shen, "Relay Selection and Resource Allocation for Multi-User Cooperative OFDMA Networks", IEEE Transactions On Wireless Communications, Vol. 12, No. 5, MAY 2013, pp.2193-2205.

[27] P. Li, S. Guo, T. Miyazaki, W. Zhuang**, "**Fine-Grained Resource Allocation For Cooperative Device-To-Device Communication in Cellular Networks",IEEE Wireless Communication, October 2014, pp.35-40.

[28] H. Al-Tous, I. Barhumi, "Distributed Resource Allocation for Multi-User Multi-Relay AF Cooperative Communication", http://digitalcommons.unl.edu/usafresearch.

[29] L. Ding, T. Melodia, S. N. Batalama, J. D. Matyjas, "Distributed resource allocation in cognitive and cooperative ad hoc networks through joint routing, relay selection and spectrum allocation", Elsevier, Computer Networks, Vol.83, 4 June 2015,pp. 315-331.

[30] M. A. Rahman, N.Parveen, " Subcarrier Analysis and Power Allocation for Cooperative Communication in LTE –Advanced Networks", International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064, Vol. 4 Issue 6, June 2015.

[31] M. A. Kareem, N. Parveen, " Effective Resource Allocation for Cooperative Communication using Water Filling Algorithm in LTE Advanced Network", International Journal of Innovative Technologies, ISSN:2321-8665,Vol.4, Issue.11,August 2016, pp.1906-1909.

[32] B. Nazari , A. Jamalipour, “Contract-auction based distributed resource allocation for cooperative communications”, IET Commun., 2016, Vol. 10, Iss. 9, pp. 1087–1095
[33] S. Hamda, M. Pischella, D. Roviras, R. Bouallegue, “Uplink resource allocation in cooperative OFDMA with multiplexing mobile relays”, EURASIP Journal on Wireless Communications and Networking (2016) 2016:215,
[34] R. Bordón, S. M. Sanchez, S. B. Mafra, R. D. Souza, J. L. Rebelatto, E. Martin, G. Fernandez, “Energy Efficient Power Allocation Schemes for a Two-User Network-Coded Cooperative Cognitive Radio Network”, IEEE Transactions On Signal Processing, Vol. 64, No. 7, April 1, 2016, pp.1654-1666.
[35] C. Xu, J. Feng , B. Huang , Z. Zhou , S. Mumtaz, J. Rodriguez, “Joint Relay Selection and Resource Allocation for Energy-Efficient D2D Cooperative Communications Using Matching Theory”, Appl. Sci. 2017, 7, 491.
[36] Guangjun Liang, Qi Zhu1, Jianfang Xin1, Ziyu Pan, “ Joint Resource Allocation Scheme for OFDM Wireless-Powered Cooperative Communication Networks”, KSII Transactions On Internet And Information Systems, Vol. 11, No. 3, Mar. 2017, pp.1357-1372.