International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Network Related Issues For Cooperative Diversity

Parvinder Bangar, Manisha Bangar

1-2 *Deptt. of Electronics & Communication Engineering, Maturam Institute of Engineering & Management, Rohtak*

Abstract- **Cooperative diversity is a network problem which can exist across several layers in layered network architecture. It has been found from continuous work on relay channel for information theory community that there are several other fields of research to build from and relate to, including single user multi-antenna systems and various results for ad-hoc networks (especially in multi-hop routing).**

***Index Terms*— Diversity, Shannon Capacity, Average Capacity, Outage, Multi antenna system.**

I. RELAY CHANNELS AND EXTENSIONS

Maximum of researchers on relay channels have focused on discrete or additive white Gaussian noise channels and their performance was examined in terms of Shannon capacity [8]. But the recent work has also considered the issue of multipath fading. The classical relay channel model was initially introduced and examined by Van Der Meulen, and then studied by a number of authors. The distinctive property of relay channels is that they receive process and re-transmit the information bearing signals to improve overall performance of system. Any extra terminal in network can serve as relay. Also, transmitting and/or receiving terminals can cooperate by serving as relays for each other.

Cover and E I Gamel developed lower and upper bounds for channel capacity via random coding and converse arguments respectively after examining non-faded relay channels. The lower and upper bounds never coincide except in the case of degraded relay channels. The lower bounds on capacity are obtained by using three structurally different random coding schemes which are facilitation, cooperation and observation [7].

The facilitation scheme is not largely involved. In this scheme, relay does not actively help the source, but supports the transmission by inducing as little interference as possible. The cooperation and observation schemes are largely involved.

In cooperation scheme, the relay terminal retransmits the information signal after fully decoding the source message. The relay precisely encodes the bin index of the previous source message according to Slepion Wolf Coding [8]. The terminal transmits the superposition of new encoded message and encoded bin index of previous source message. The destination terminal combines the source and relay transmissions in order to achieve higher rates than with direct transmission alone. In some cases, the full decoding of signal at relay terminal can be a limiting factor because the transmission rates achieved by this type of cooperation are not greater than capacity of direct transmission. Cover and E I Gamel offered observation scheme as an alternative. In observation scheme, the relay encodes a quantized version of its received signal.

At destination, relay's signal and direct source message signals are combined for better estimation of source message. Simply it can be said that cooperation scheme may be most beneficial when channel between source, relay and destination is particularly good. But for intermediate regions, superposition of two schemes can be implemented for maximizing the available rates. There are two general cases of relay processing and retransmission.

In one case, the relay decodes the received signal and retransmits some information about received signal which is referred as decode-and –forward scheme [7], e.g. regenerative repeaters. In other case, the relay conveys the representation of received signal to destination so that destination effectively combine two receive signals and decode. This is referred as observe-and-forward schemes [30], e.g. amplifying repeaters.

II. FADING CHANNEL CAPACITY

Several types of capacities have been developed because of the conditions under which wireless systems operate [4]. These include –

- Shannon (Ergodic) capacity
- Capacity- Vs.- Outage
- Average Capacity

These capacities are significantly influenced by two factors. First, the extent to which fading changes during coding interval. Second, the availability of channel state information at terminals. Let us consider a single-user additive white Gaussian noise (AWGN) channel with frequency non-selective fading property for describing various capacities. The channel can be modelled in complex baseband equivalent form as under-

$$y[n] = a[n].x[n] + z[n] \tag{1}$$

Where x[n] : transmitted signal

a[n] : effects of multipath fading

z[n] : receiver’s thermal noise and other forms of interference

A. SHANNON CAPACITY

Ergodic fading (Full Temporal Diversity)

If a[n] is a stationary and ergodic process and coding is performed over long block lengths, then Shannon capacity becomes a measure of maximum rate of reliable communication. Reliable communication is that when error probabilities approaches to zero. Depending upon fading state information available at receiver or transmitter, Shannon capacity appears differently. Fading may be treated as an additional channel output if only receiver measures the fading process with precision. The mutual information between input and output will be given by-

$$I(x;y;a) = I(x;a) + I\left(x;\frac{y}{a}\right) \tag{2}$$

If z[n] is independent and identically distributed (i.i.d.) complex Gaussian with variance N_0 and x[n] is i.i.d complex Gaussian with variance P, then the mutual information in “(2)” will become channel capacity [9].

$$C_{CSIR} = E\left[\log\left(1 + \frac{|a|^2 P}{N_0}\right)\right] \tag{3}$$

If a separate feedback channel exists, then transmitter can adapt x[n] to channel states. A simple adaption rule must be followed. If SNR falls below a certain threshold, then there should be no transmission and there should be high power transmission if SNR lies above threshold [8].

Adaptations must be according to appropriate average or peak power constraints. Generally, Shannon capacity in Gaussian noise [12] is given by-

$$C_{CSIR,CSIT} = \max_{P(.)} E\left[\log\left(1 + \frac{|a|^2 P(a)}{N_0}\right)\right] \tag{4}$$

Where P (.) represents power allocation function, e.g. an average power constraint $E[P(a)] \leq P$

Non-Ergodic Fading, No Temporal Diversity

In some circumstances, fading process may be non-ergodic within coding interval due to delay constraints on system and in case of stationary environments. The lack of temporal variations in the channel prevents the coding strategy from exploiting temporal diversity. In such cases, Shannon capacity is often zero, therefore it is not a useful performance measure. Shannon capacity breaks down due to non reliable communication. There are another performance measures which depend on probability distribution over channels in composite channel framework [24].

B. CAPACITY-VS.-OUTAGE

Capacity-vs.-outage is trade-off between fixed rate and probability of achievable rate over any composite channel. Let us consider non-ergodic Gaussian fading channel for any fixed rate R and same channel realizations supporting the rate with-

$$\log\left(1 + \frac{|a|^2 P}{N_0}\right) \geq R \tag{5}$$

Also, some channel realization will not support the rate, which is with

$$\log\left(1 + \frac{|a|^2 P}{N_0}\right) < R \tag{6}$$

The event in “(6)” is referred as an outage event and its probability is called as outage probability of channel. Outage probability should be a non-decreasing function of R.

In Gaussian case, this condition is satisfied. Hence, the capacity-vs.-outage is defined as maximum rate of outage probability less than some predetermined level. Delay limited capacity is the special case of capacity-vs.-outage corresponding to zero outage [27, 38, 6].

C. AVERAGE CAPACITY

In the capacity-vs.-outage framework, coding and modulation are performed at some fixed, pre-determined, achievable or non-achievable rate. Another option for coding and modulation is coding for a monotonically increasing set of rates by using general superposition codes for broadcast channel. Rates are achievable only up to a certain point depending upon channel realization. This will further result in designing of a coding scheme for maximizing the expected achievable rate. The average capacity framework may be useful only if it is paired with appropriate source-coding techniques, e.g. successive refinement coding [29] and approach was originally proposed for fading channels [31].

III. MULTI-ANTENNA SYSTEMS

Now-a-days, there is an increase in the use of multi-antenna physical arrays at transmitter and receivers. These physical arrays offer space diversity to overcome fading and beam forming (to overcome fading and interference both). Increased capacity and improved robustness to fading are advantages to physical arrays. Due to these benefits, special efforts have been made for designing of practical space-time codes and their decoding algorithms. Various studies have proved that carrier frequency wavelength dependent separation among antennas plays an important role for spatial diversity with physical arrays. The constraints will be less effective with an increase in carrier frequency. The decrease in terminal size with circuit integration will limit the number of antennas for transmitter or receiver. For such size constraint system, a virtual array is created by using multiple users in cooperation and effective sharing of their antennas.

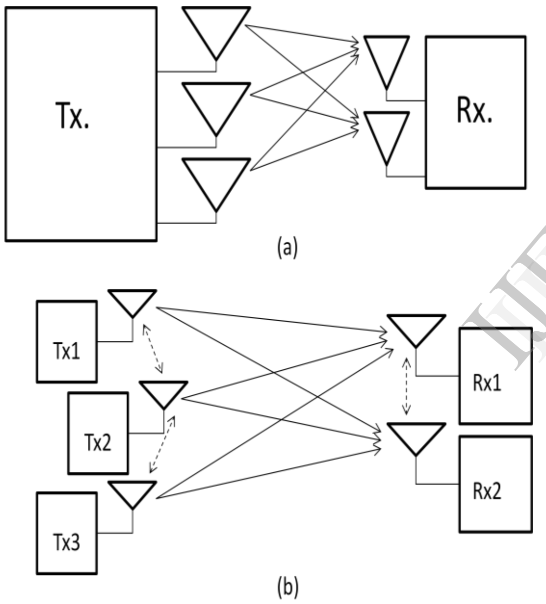

Fig.1 Block Diagram of point-to-point physical array. (a) multi-user virtual array and (b) cooperative diversity transmission.

Fig.3.1 is a comparison of block diagrams for physical and virtual arrays. Physical layer is responsible to handle multi-antenna array problem, but virtual arrays can be handled with a variety of layering including interaction across layers. Multi-antenna physical array systems provide performance bounds for virtual array. Also, space-time code of physical arrays can be used in cooperative settings.

Fig.2 is illustrating a model for multi-antenna system having T transmitters and R receivers. In vector form,

$$y = Ax + z \tag{7}$$

Where A is R*T matrix

y and z are column vector of size R*1

x is column vector of size T*1

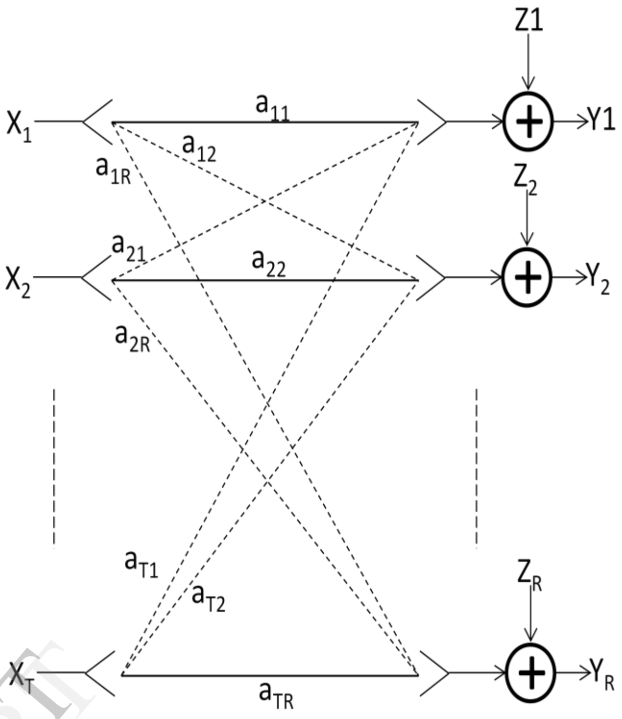

Fig.2 Multi antenna system

Here, any element $[A]_{r,t} = a_{r,t}$ is responsible to capture the effects of multipath fading between transmitter t and receiver r and zr is responsible for receiver's thermal noise and other forms of interference.

The model shown in fig.2 is special case of wireless network having one transmitter and one receiver with input and output vectors. The model has been greatly improved. Initially, focus was on multiple receiver antenna with associated algorithms and array processing techniques (beam forming and interference mitigation) [19, 28], but recently the systems having multiple transmitter antenna with multiple receiver antenna have been developed.

Researchers have focused on characterization of limits on performance of multi-antenna system and designing of practical coding and decoding algorithms to follow these limits.

A. FUNDAMENTAL PERFORMANCE LIMITS

The limiting performance of multi-antenna system was characterised after several studies under large number of fading conditions. The Shannon capacity for channel model in fig.3.2 was developed for several different cases of channel state information available to transmitter and receiver:

- Without channel state information [1, 2, 25, 40]
- With channel state information available to receiver only [26]
- With channel state information available to both transmitter and receiver [35]

B. SHANNON (ERGODIC) CAPACITY

According to Shannon capacity, capacity increases in multi-antenna systems. If the channel state information is available only at receiver, then Shannon capacity increases by min {T, R} b/s/Hz for each additional 3dB of SNR in high SNR region [35]. If no channel state information is available, then channel capacity will depend upon-

- Number of transmitting antenna
- Number of receiving antenna.
- Channel coherence time, k (defined as number of samples for which any channel remains constant in assumed block fading model before it changes)

Also the capacity of an AWGN (Additive White Gaussian Noise) channel increases by 1b/s/Hz for each additional 3dB SNR in high SNR region. Therefore, large efficiencies can be achieved by use of multi-antenna systems.

C. CAPACITY-VS.- OUTAGE AND DELAY LIMITED CAPACITY

Any channel may not exhibit ergodic nature within a coding interval (when delay constraints are considered), therefore, Shannon capacity is zero. In such cases outage probability [5, 27] or delay limited capacity [15] are used to measure efficiency of multi-antenna system. In addition of increased capacity, multi-antenna systems can be used to improve robustness to fading conditions. [11, 26, 35]

Various studies examined the coding and decoding methods (space time codes) to increase spectral efficiency in case of multi-antenna systems. Scalar coded methods were in use for earlier schemes, e.g. repetition diversity over orthogonal frequency band [26]. Vector coding was a result of studies on BLAST systems by Foschini and Gans [10, 11].

Space time and block codes were given by Tarokh [33, 34]. Differential space time coding was result of Hochwold and Marzetta [16, 17, 18]. Simple block codes (to achieve full diversity) and simple linear decoding algorithms were given by Alamouti [3].

IV. WIRELESS NETWORKS

Cooperative diversity may primarily be implemented in radio terminal networks and network architectures which are involved for proper function. Also, depending upon application and pre-existing infrastructure, these architectures may be of different forms. Following results have been obtained for infrastructure networks and ad-hoc networks.

A. INFRASTRUCTURE NETWORKS

Keeping in view, the fundamental performance limits at physical layer, infrastructure networks are treated primarily at cell level (inter-cell interference is treated as noise). The uplink transmission is modelled as multiple-access channel with multiple-antennas and channel state information at base station. The downlink transmission is modelled as without multiple-antennas; channel state information at mobiles and inter-cell interference.

Earlier, cellular uplink models were treated without fading and with inter-cell interference by allowing all base stations to cooperatively decode transmissions from mobiles [39]. It was also determined that performance of intra-cell TDMA was sufficient, but performance of inter-cell TDMA degraded. Depending upon this model, fading was measured at receivers and their associated inter-cell issues were examined. Different forms of power control in network were allowed by measuring the fading by receivers and fed back to transmitters [12, 23, 37]. This multi-user diversity was translated into total throughput of a multiple-access channel. These results were, further, extended to downlink channels and other forms of channel capacity.

B. AD-HOC NETWORKS

Ad-hoc networks were introduced as packet radio networks [20, 21], which was a wireless extension of packet switching in wire-line networks. The issues were re-examined due to technological advances. A number of authors have compared direct (single-hop) transmission and cascade (multi-hop) transmission by considering channel conditions [36]. Some authors examined another issues like scheduling, routing and organisational problems associated with these networks [22].

Basically, ad-hoc networks were developed by computer and data networking communities. But, some performance and scaling laws were introduced by information theory community. High data rates can be obtained by using fixed networks of small numbers of terminals (to make efficient use of large bandwidths) without any sophisticated network protocol [14, 32].

Suitable cascade transmission policy (which provides throughput of 1 per terminal as network density increases) was developed by Grossglauser [13] depending upon [14]. According to mobile protocol, at any given time, a terminal transmits packets (its own packets or forwarding packets of another terminal) only to its closest (nearest) terminal. Due to increase in terminal density, the transmission distance will decrease, which further results in low power requirement and less interference. In broader sense, every terminal is carrying queued packets for every other terminal. Therefore, it can be said that protocol is offering multi-user diversity effect.

Emerging research is resulting in some new interior points. Some authors have explained throughput capacity per terminal with higher terminal density within a constant area [13, 14]. Some worked on an achievable rate region for multi-hop routing for finite number of terminals. Others introduced rate vectors for negative rates depending upon forwarding information for another terminal.

V. CONCLUSION

Here, we have evaluated the wireless network algorithm by considering the cooperation among terminals. A number of relay terminal signals form virtual antenna array for each other, which further led to trade-off between cost, power, bandwidth and computational complexity. Also, there is a trade-off between cooperating terminals with their own information to communicate. To overcome multipath fading spatial diversity was implemented. In contrast to classical relay channel model, it is having a single source terminal with information to communicate and additional relay terminals without information to communicate. Here, the relay can be additional resource of power and computation and can be used by source terminal. Also, there is no trade-off which again supports cooperative diversity.

REFERENCES

[1] Ibrahim Abou-Faycal, Mitchell D. Trott, and Shlomo Shamai (Shitz), “The capacity of discrete-time Rayleigh fading channels” in Proc. IEEE Int. Symp. Information Theory (ISIT), p. 473, 29 June - 4 July 1997.

[2] Ibrahim C. Abou-Faycal, Mitchell D. Trott, and Shlomo Shamai (Shitz), “The capacity of discrete-time memoryless rayleigh-fading channels” IEEE Trans. Inform. Theory, pp:1290-1301, May 2001.

[3] Siavash Alamouti, “A simple transmit diversity technique for wireless communications” IEEE J. Select Areas of Communication, pp:1451-1458, October 1998.

[4] Randall A. Berry, “Power and Delay Trade-Offs in Fading Channels” PhD thesis, MIT, Cambridge, MA, June 2000.

[5] Ezio Biglieri, John Proakis, and Shlomo Shamai (Shitz), “Fading channels: Information theory and communications aspects” IEEE Trans. Inform. Theory, pp: 2619-2692, Oct 1998.

[6] Giuseppe Caire, Giorgio Taricco, and Ezio Biglieri, “Optimum power control over fading channels” IEEE Trans. Inform. Theory, pp:1468-1489, July 1999.

[7] Thomas M. Cover and Abbas A. El Gamal, “Capacity theorems for the relay channel” IEEE Trans. Inform. Theory, pp: 572-584, September 1979.

[8] Thomas M. Cover and Joy A. Thomas, “Elements of Information Theory” John Wiley & Sons, New York, 1991.

[9] Thomas H. E. Ericson, “A Gaussian channel with slow fading” IEEE Trans. Inform. Theory, pp: 353-355, May 1970.

[10] Gerard J. Foschini, “Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas”. Bell Syst. Tech. J., pp: 41-59, 1996.

[11] Gerard J. Foschini and Michael J. Gans, “On limits of wireless communications in a fading environment when using multiple antennas”

[12] Andrea J. Goldsmith and Pravin P. Varaiya, “Capacity of fading channels with channel side information” IEEE Trans. Inform. Theory, pp: 1986-1992, November 1995.

[13] Matthias Grossglauser and David N.C. Tse, “Mobility increases the capacity of ad-hoc wireless networks” IEEE/ACM Trans. Networking, March 2001.

[14] Piyush Gupta and P.R. Kumar, “The capacity of wireless networks” IEEE Trans. Inform. Theory, pp: 388-404, March 2000.

[15] Stephen V. Hanly and David N.C. Tse, “Multi access fading channels -Part II: Delay-limited capacities” IEEE Trans. Inform. Theory, pp: 2816-2831, November 1998.

[16] Bertand M. Hochwald and Wim Sweldens, “Differential unitary space-time modulation” IEEE Trans. Commun., pp: 2041-2052, December 2000.

[17] Bertrand M. Hochwald and Thomas L. Marzetta, “Unitary space-time modulation for multiple-antenna communications in rayleigh at fading” IEEE Trans. Inform. Theory, pp: 543-564, March 2000.

[18] Bertrand M. Hochwald, Thomas L. Marzetta, Thomas J. Richardson, Wim Sweldens, and Rudiger Urbanke, “System design of unitary space-time constellations” IEEE Trans. Inform. Theory, pp: 1962-1973, September 2000.

[19] William C. Jakes and Donald C. Cox, “Microwave Mobile Communications” IEEE Press, New York, 1994.

[20] R. E. Kahn, “The organization of computer resources into a packet radio network. IEEE Trans. Commun., pp:169-178, January 1977.

[21] R. E. Kahn, S. A. Gronemeyer, J. Burch_el, and R. C. Kunzelman, “Advances in packet radio technology” IEEE Proc., pp:1468-1496, November 1978.

[22] Hisham Ibrahim Kassab, “Low-Energy Mobile Packet Radio Networks: Routing, Scheduling, and Architecture” PhD thesis, MIT, Cambridge, MA, November 1999.

[23] Raymond Knopp and Pierre A. Humblet, “Information capacity and power control for single-cell multiuser communications” in Proc. IEEE Int. Conf. Communications (ICC), volume 1, pp: 331-335, Seattle, 1995.

[24] Amos Lapidoth and Prakash Narayan, “Reliable communications under channel uncertainty” IEEE Trans. Inform. Theory, pp: 2148-2177, October 1998.

[25] Thomas L. Marzetta and Bertrand M. Hochwald, “Capacity of a mobile multiple antenna communication link in rayleigh at fading” IEEE Trans. Inform. Theory, pp:139-157, January 1999.

[26] Aradhana Narula, Mitchell D. Trott, and Gregory W. Wornell, “Performance limits of coded diversity methods for transmitter antenna arrays” IEEE Trans. Inform. Theory, pp: 2418-2433, November 1999.

[27] Lawrence H. Ozarow, Shlomo Shamai (Shitz), and Aaron D. Wyner, “Information theoretic considerations for cellular mobile radio” IEEE Trans. Veh. Technol., pp:359-378, May 1994.

[28] John G. Proakis, “Digital Communications” McGraw-Hill, Inc., New York, Third edition, 1995.

[29] Bixio Rimoldi, “Successive refinement of information: Characterization of the achievable rates” IEEE Trans. Inform. Theory, pp: 253-259, January 1994.

[30] Brett Schein and Robert G. Gallager, “The Gaussian parallel relay network” in Proc. IEEE Int. Symp. Information Theory (ISIT), page 22, Sorrento, Italy, June 2000.

[31] Shlomo Shamai (Shitz), “A broadcast strategy for the Gaussian slowly fading channel” in Proc. IEEE Int. Symp. Information Theory (ISIT), page 150, Ulm, Germany, June 29-July 4 1997.
[32] Timothy J. Shepard, “Decentralized Channel Management in Scalable Multihop Spread Spectrum Packet Radio Networks” PhD thesis, MIT Cambridge, MA, July 1995.
[33] Vahid Tarokh, H. Jafarkhani, and A. Robert Calderbank, “Space-time block codes from orthogonal designs” IEEE Trans. Inform. Theory, pp: 1456-1467, July 1999.
[34] Vahid Tarokh, Nambi Seshadri, and A. Robert Calderbank, “Space-time codes for high data rate wireless communication: Performance criterion and code construction” IEEE Trans. Inform. Theory, pp: 744-765, March 1998.
[35] I. Emre Telatar, “Capacity of multi-antenna Gaussian channels” European Trans. On Telecomm pp: 585596, Nov-Dec 1999.
[36] Fouad A. Tobagi, “Modeling and performance analysis of multihop packet radio networks” Proc. IEEE, pp: 135-155, January 1987.
[37] David N.C. Tse and Stephen V. Hanly “Multi access fading channels - Part I: Polymatroid structure, optimal resource allocation and throughput capacities” IEEE Trans. Inform. Theory, pp: 2796-2815, Nov 1998.
[38] Sergio Verdu and T. S. Han, “A general formula for channel capacity” IEEE Trans. Inform. Theory, pp: 1147-1157, July 1994.
[39] Aaron D. Wyner, “Shannon-theoretic approaches to a Gaussian cellular multiple access channel” IEEE Trans. Inform. Theory, pp: 1713-1727, November 1994.
[40] Lizhong Zheng and David N.C. Tse, “Communication on the Grassmann manifold: A geometric approach to the non-coherent multiple-antenna channel” IEEE Trans. Inform. Theory, pp: 359-383, February 2002.