Exploring the Optimization Technology Scheme in Complex Networks for the Cooperative Wireless Communication

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May 27, 2019

***Abstract*--**With the increase in the undeniable growth demand of the users for the bandwidth in the wireless communication system (WCS), this is indeed an era of high speed, high bandwidth and high frequency trends. The area is wide open to study and implement the cooperative communication optimization techniques for the complex networks using a multiple transmit antenna array to form a MIMO (Multiple Input Multiple Output) system. In this paper, the research clarifies that there is no need to expand the resources of the spectrum and the antenna transmission power in order to get more benefits in the cooperative system. It is far better to enlarge the channel capacity, make the substantial improvements in the security and reliability of the transmission of the communication. This can be applied to the cellular communication and wireless sensor networks as well. Thus, it can better predict, optimize and control the networks that are based upon the cooperative communication. In the later stages of the paper, the fading nature of a wireless system is discussed and it is proved by using Jensen's inequality that the average bit error rate (BER) in wireless systems is always greater than the BER in the wireline system.

Keywords: wireless communication system; complex networks; cooperative communication; convex optimization, Bit Error Rate, Diversity.

Introduction:

Complex networks invade our everyday life. These span from biological networks such as metabolic network representing interactions between metabolites and enzymes responsible for growth and maintenance of a cell, to transportation networks such as the road, rail and airline network linking cities across the world, to social networks such as Facebook linking individuals based on their friendships [1]. In the context of wireless network i.e. the advanced form of the complex networks, the concept of using cooperative communication through the relays has the significant advantage [2]. There is a rapid development and very swift improvement in this field as to overwhelm the demands of the users who utilize the system. There exists an immense need to constantly refine the transmission rate of the wireless communication while ensuring its rapid expansion. On the other hand, the phenomenon of robustness should be kept in mind as to keep the network connected despite the loss of nodes and edges due to any reason. Thus, due to the prevalence of complex networks, a topic of interest has been the robustness of such networks to disruptions, both in the structure and in the dynamics that are occurring on the network [3]. In [4], every potential relay's ability for cooperation is measured after the allocation of power between the relay and the source node. The constant improvement in the transmission of a wireless communication has spawned more advanced and an efficient communication. However, during this improvement, QoS (Quality of Service) standards cannot be neglected. So, the use of relay in the cooperative communication has notable advantages. In this regard, some of the contemporary relay selection strategies which can be practically implemented include pre-selecting one relay among the others, selecting the best relay depending upon some criterion, and selection of relay in a cooperative manner [2]. In [5], a very fascinating phenomenon of emphasizing on models is discussed where individuals can move from one compartment to another randomly with some defined rates. It is interesting to know that in this two compartment model healthy individuals can randomly pass from S (susceptible compartment) to I (Infected Compartment) with some infection rate that is an outcome of interactions with infected individuals. Similarly, infected individuals can randomly transfer from I to S with some recovery rate that is a result of recovering from the infection [5]. It is also observable that communication in a wireless environment is highly unreliable. So, BER (Bit Error Rate) in a wireless network is significantly higher as compared to a wireline system. It happens just due to the non-linear nature of fading channel in a wireless communication. Hence, to overcome this fading nature, there is an enormous need of some technologies. One of the salient technology is known as Diversity. A most typical example of the Diversity is the Multiple Antenna System. This fading nature of a wireless system can be revamped by using the relays in the cooperative network. This can be achieved by using the link prediction technique. Link prediction in complex networks has attracted increasing attention from both physical and computer science communities. The algorithms can be used to extract missing information, identify spurious interactions, evaluate network evolving mechanisms, and so on [6]. For example, in Fig. 1, there are three nodes shown in the cooperative system model while considering only single relay i.e. Source Node (S), Relay Node (R) and the Destination Node (D). The Cooperative Communication is divided in to two phases: In the Phase 1, the Source node broadcasts the information and it is relayed by the both Source node and the destination. In phase 2, the relay amplifies the received signal and forwards it to the Destination node (Target node).

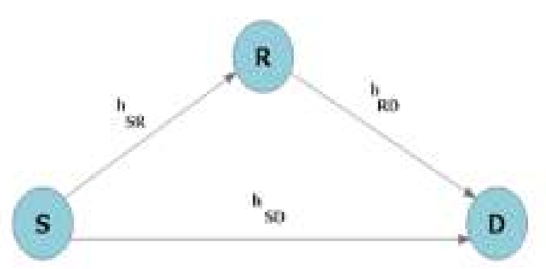

Fig. 1: System Model

There are some other techniques that are been proposed to subjugate this issue. For example, in [7], the users are allowed to choose the cooperating partners on the basis of the priority list. But there still exists the problem in the algorithm because it still depends upon the fading nature of the wireless communication which bars the relaying schemes to achieve the full diversity [2]. Whenever a relay is selected then it will broadcast a flag packet to inform other relays to stop communicating [8]. In [9], they proposed a new scheme that confers relays a decision making scheme on the motive of the proposed SNR threshold method. So, from the technologies like signal processing, wireless and mobile communication, detection technology, diversity etc. we take the cooperative diversity as an example here. It is based upon multiple inputs and multiple outputs (MIMO).

1. Complex Networks and Cooperative Communication

The ubiquity of complex networks in science and technology has organically led to a set of customary and key research problems concerning how the network structure assists and constrains the network dynamical behaviors, which have largely been neglected in the studies of traditional disciplines [10]. The Cooperative Communication and the Complex Networks are analyzed as follows.

1.1 The Current Condition of the Cooperative Communication

As we experience that, the entire network communication between the devices is based upon a layered architecture. The Cooperative Communication includes the physical layer, data-link layer, network layer, access-control layer etc. The establishment of wireless relay cooperative communication can strengthen the transmission rate, Hence, the sensitivity of the fading channel changes is reduced and the network coverage is significantly enhanced. This Cooperative Communication research emphasizes on the following aspects: (I) Scheme Design and performance analysis; (II) Power resources, time slot resources and bandwidth resources distribution problem; (III) The selection problem of the relay node; (IV) Differential implementation and synchronization; (V) The most recent problem i.e. Frequency selective fading.

1.2 The position of the Complex Networks

It is being noticed that understanding and analyzing the network topology is portraying a very unremarkable role to pinpoint the important nodes that are helpful to spread the information very rapidly in the network [11], [12]. A method to select the predominant nodes in a large and complex network based upon the community structure and degree of neighbor was proposed in [13]. The complex networks are literally the abstract methods of the actual complex system phenomenon. Discovering the powerful nodes to spread information in the complex network is an influential issue for the researchers.

2. Complex Network Model

2.1 Systematic network model

The systematic network model basically governs the relationship between the internal components of a complex system. It can be revealed as a global coupled network model, proximity coupled network model, star shape network model etc. Its common characteristic is the higher clustering coefficient.

2.2 Arbitrary network model

As expressed earlier, the rule network model is acceptable for complex systems with the fixed algorithms. Hence, it is very demanding to describe the complex network phenomenon accurately. For this reason, we use the arbitrary model i.e. the method of the analysis based upon the probabilities to resolve the problems in the complex networks. This can also be called as the non-linear analysis of network modeling.

2.3 Compact network model

We establish a compact network model to achieve the phenomenon for shorter average path lengths and higher average clustering coefficients in complex networks.

2.4 Scale-independent network model

To better explain the actuality of the complex system networks, we use a scale-independent network model. Because, complex network systems are inconsistent and have no considerable feature path length. So this non-uniformity and non-considerable path length can be analyzed according to power-law distribution characteristics to assemble a scale-independent network. This model better explains the authenticity of the complex system networks.

3. Key optimization technology factors of the collaborative communication in complex networks

Based on the current high rate of communication services, diversified progression of the situation, it is an immense need to provide high Broadband wireless communication with high transmission rate and high spectrum efficiency. It can be achieved by making the full use of multi-antenna (MIMO) Technology and collaborative communications technology to encounter the needs of complex networks.

3.1 Features of indispensable technologies of collaborative communication

The collaborative wireless communication technology is a brand new way of communication which has many advantages especially:

1) **Gain:**

Collaborative wireless communication can pass set gain, multiplexing gain, path loss gains etc., reduce transmission power, expand channel capacity and increase its coverage. Cooperative wireless communication is a very novel approach which has countless applications in wireless communication systems (W.C.S) and signal processing (S.P). It should be kept in mind that we always consider the perspective of electronic steering in wireless communication systems because it is efficient, reliable, less expensive and productive as well. On the other hand, the mechanical steering is very expensive and less productive. We have the stereotype equation (1) i.e.

$$\vec{y} = H\,\vec{x} + \vec{n} \qquad (1)$$

$where, \overline{y} = recieved\ symbols\ vector$

$H = fading\ channel\ vector$

$\vec{n}\ = noise\ vector$

$x = transmit\ symbol$

We have another equation (2) with the vector $\vec{w}$ that is used for applying the optimization. So, for a highly optimized system, there must be an optimal $\vec{w}$.

$$\vec{w}^H\,\vec{y} = \vec{w}^H\,H\,\vec{x} + \vec{w}^H\,\vec{n} \qquad (2)$$

The combination of $\vec{w}^T\,H$ in equation (2) is basically considered as the gain/power of the signals.

2) **Balance**:

Relay selection in a collaborative communication environment can preferably balance the difference between the edges and the center of the section ensuring that both balance the quality and effectiveness of consistent communication processes. In a MIMO system we have the multiple antennas of T_x (Transmission) and R_x (Receiving). The Maximal Ratio Combiner in a MIMO system can be defined with the help of following equation.

$$\vec{w} = \frac{H}{||H||^2} \qquad (3)$$

We have a T_x beamforming vector i.e. $\vec{V}$ and it can be used as:

$$\vec{x} = \vec{V}\, x \qquad (4)$$

Inserting the value of $\vec{x}$ in (1), we get,

$$\vec{y} = H\vec{V}\, x + \vec{n} \qquad (5)$$

Now, to balance the quality and effectiveness of the communication process we have the R_x beamforming vector i.e. $\vec{U}^H$. So, just like the equation (2), we get another equation by putting the value of $\vec{y}$ in $\vec{U}^H\vec{y}$:

$$\vec{U}^H\vec{y} = \vec{U}^H\left(H\vec{V}\, x + \vec{n}\right) \qquad (6)$$

Both the beam formers of T_x and R_x are jointly determined as to maximize the SNR (Signal to Noise Ratio) of the system. Use of the relay scheme in this MIMO scenario subsequently creates a generous balance in the wireless communication.

3) **Realize the network with insufficient basic conditions**:

A relay basically gets the signal, performs some simple or complex manipulations, and then re transmits the signal to the destination. It significantly strengthens the performance of the wireless communication system. The relay selection technology of collaborative communication can break through the basic conditions in order to validate the deployment of a fast and reliable relay network. For example, the protocols like AF (Amplify and Forward) and DF (Decode and Forward) conclude the same.

4) **Favorable Cost:**

The collaborative communication can support a method of setting a special fixed relay station that reduces the equipment acquisition costs, transmission costs and as well as minimize the network deployment and operating cost.

However, it is appropriate to mention that collaborative communication also inevitably has its own defects and deficiencies. Due to the substantial number of users and relay nodes in the cooperative communication network, it widens the difficulty of scheduling and requires complex scheduling algorithms and schedulers. In this regard, the scheduling of access users and data flow forwarding is implemented. If the scheduling is not credible enough, then It will offset all the gains provoked by the physical layer cooperation. On the other hand, the relay selection is very burdensome because the relay selection strategy in the cooperative communication is tough to estimate the dynamic distance. The collaborative communication technology for mobile environments is lacking in the optimal relay transmission and coordination is based upon cooperative diversity. In addition to all this, the interference (especially in the wireless communication) of the wireless signals is the principal reason which is basically influencing the performance of the complex networks. There exists an enormous involvement of signal switching, synchronization, security implementation etc. in cooperative communication. It makes the network processing more complicated and hence increasing the cost of the collaborative communication network. Another technique i.e. Distance-based relay selection technology also has redundant transmissions like this [1]. This phenomenon also adjoins extra relay links to complex networks, requiring additional frequency signals. The support of the channel or time slot leads to a reduction in network throughput. The increase in the nodes is not beneficial to the implementation of delay-sensitive services such as voice and video.

3.2 Fundamental Technologies for collaborative communication

3.2.1 Collaborative Diversity Technology with Jensen's Inequality

Diversity technology is actually a phenomenon between the nodes that does not directly deal with source-relay, relay-destination schemes. The fading channel phenomenon in the wireless communication can be refined by using the diversity technology to acquire the high-order diversity gain between the users to minimize the transmit power and enhance the MIMO system. Multiple signal copies are combined to enhance SNR as well as reliability of a wireless system. Specifically, the collaborative diversity technology consists of two parts:

1- Two end users send and receive symbols at the same time.
2- Two end users process the received signals, then the processed signals are sent to receiving end.

The main performance of the collaborative diversity technology is as follows.

Zoom-forward: The signal at the terminal is simply amplified, and then the received signal is forwarded, which provokes a signal with most probably the huge noise.

Decode-forward: This method simply performs some operations on the signal sent by the terminal. Symbol-by-symbol detection and generation of new symbols is performed in this process. It is pertinent to mention that in Decode-Forward; signal/symbol must be re-transmitted correctly/accurately [1].

The root of all this is the fading nature of the wireless communication system. It can be solved by using the Jensen's inequality as it can demonstrate the poor working of W.C.S. The Jensen's inequality for the convex functions and concave functions is shown in equation (7) and (8) respectively.

$$F\{E(\vec{x})\} \leq E\{F(\vec{x})\} \tag{7}$$

$$F\{E(\vec{x})\} \geq E\{F(\vec{x})\} \tag{8}$$

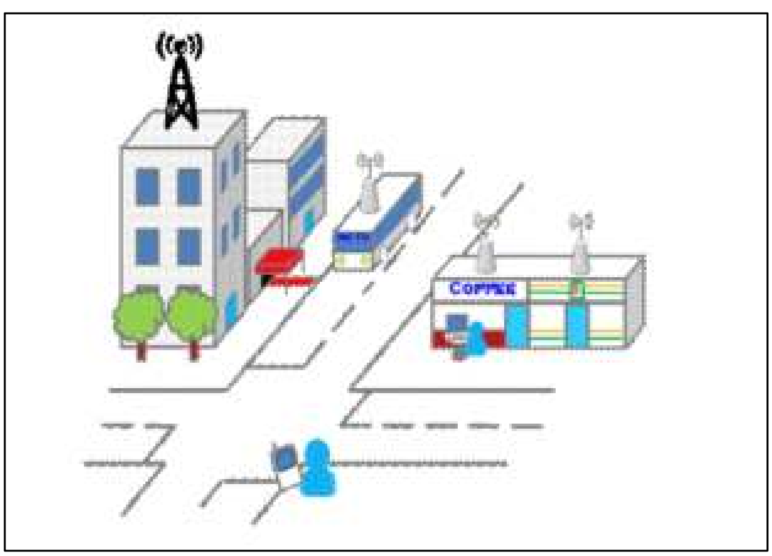

Fig. 2 The fading nature of a wireless system

The Fig. 2 shows that there is a significant interference in a wireless communication. As a wireline system has one direction, but a wireless system scatters everywhere. This is the reason why we use a fading channel coefficient in a wireless system as utilized in equation (1). SNR for a wireless system can be shown by the following equation.

$$SNR = \frac{P}{\psi} \; |h|^2 \qquad (9)$$

Assuming that $\frac{P}{\psi} = \Delta$, So (9) becomes,

$$SNR = \Delta \; |h|^2 \qquad (10)$$

We will set $\mathrm{E}\{|h|^2\} = 1$ for fair comparison between wireless and wireline systems.

So, E{SNR} = E{$\Delta \; |h|^2$}

Bit error rate (BER) or probability of BER in a wireless communication system is:

$$BER = Q\,\sqrt{SNR} \qquad (11)$$

Equation (11) can be written as:

$$BER = Q\,\sqrt{\Delta\;|h|^2} \qquad (12)$$

Since, the Gaussian Q-function is written as:

$$Q\,(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} . e^{-t^2/2} \; .dt \quad (13)$$

Replacing x with $\sqrt{x}$ in (13), we get,

$$F\,(x) = Q\left(\sqrt{x}\right) = \int_{\sqrt{x}}^\infty \frac{1}{\sqrt{2\pi}} . e^{-t^2/2} \; .dt \quad (14)$$

We suppose that, $F\,(x) = \; Q\left(\sqrt{x}\right) = \int_{\sqrt{x}}^{\infty} \frac{1}{2\pi} . e^{-t^2/2} \; .dt$, and we already know that $Q\,(x)$ is always a convex function. Now we will prove that $F\,(x) \; or \; Q\left(\sqrt{x}\right)$ is also a convex function by using the Jensen's inequality. Taking the first derivative of (14),

$$\frac{d}{dx} F\,(x) = -\frac{1}{2\sqrt{x}} . \frac{1}{\sqrt{2\pi}} . e^{-\frac{x}{2}} \quad (15)$$

Taking the second derivative on (15), we get,

$$\frac{d^2}{dx^2} \; F\,(x) = \; -\frac{1}{2\sqrt{2\pi}} . \left(-\frac{1}{2x^{\frac{3}{2}}}\right) . e^{-\frac{x}{2}} \; (16)$$

After some calculations on (16), we get the result $\frac{1}{4\sqrt{2\pi}} . \frac{1}{x^{\frac{3}{2}}} . e^{-\frac{x}{2}} \geq 0 \; (For \; all \; x \geq 0)$ hence making it clear that $\frac{d^2}{dx^2} \; F\,(x) \geq 0$ which shows that $Q\left(\sqrt{x}\right)$ is also convex.

Now, according to equation (7) i.e. $F\{E(\vec{x})\} \leq E\{F(\vec{x})\}$, it can be derived that $E\{F(\vec{x})\} = Q(\sqrt{x}) = E\{Q\sqrt{\Delta\,|h|^2}\}$.

This implies that, $E\{F(\Delta\,|h|^2)\} \geq F\{\Delta\} \geq Q\sqrt{\Delta}$ (17)

Where, $Q\sqrt{\Delta}$ is the BER of the conventional wireline system.

The equation (17) proves that the average bit error rate for wireless systems is always greater than the average bit error rate in the wireline systems.

3.2.2 Relay Selection Technology

There is an extensive need of selecting the ideal relay in a cooperative communication. For this purpose, there is a need to use the suitable technology in the dynamic relay node cooperative communication to achieve adequate power allocation as to improve the received signal power and optimize the effect of signal transmission quality. In the cellular mobile complex networks, the three vital cooperative relay structures are used i.e. 1) Cooperative Multipoint (CoMP) structure, which is basically the information exchange between the multiple points. 2) Fixed relay structure, in which the relay nodes are kept fixed through the mutual cooperation to achieve the information exchange and transmission. 3) Mobile relay structure, in which relays are in the moving mode which enables the information exchange dynamically to attain the more benefits of the diversity.

4. Probing the Cooperative Communication Optimization Technology in MIMO Relay System

In the cellular complex networks, since the base station is usually setup in the area which makes the signal power at the edge of the cell relatively weak. To control this problem, the number of base stations is also increased by means of adjoining relay stations that are evenly distributed. The communication of the base station and relay station is accomplished in the circumferential area. This makes a reasonable enhancement in the signal quality at the edge of the cell.

4.1 Optimization Design review of MIMO Single Relay System

MIMO single relay system shows that the base station is implemented by a fixed relay station. The multiple antennas are used for the amplification of the signals, decoding and forwarding [2]. The fundamental goal for this activity is to make the communication capacity greater and significantly upgrade the system performance. It also makes the communication capacity of the wireless beamforming method greater than the spatial multiplexing mode.

4.2 Optimization Design inspection of MIMO Multi-Cell Cooperative System

MIMO multi-cell collaboration system basically joins the multi-cell cooperation and relay in order to accomplish the best signal transmission between the relay-end and the end-user. In the optimization design of the MIMO multi-cell collaboration system, the very widespread technique i.e. Zero-Forcing method is used. In ZF (Zero Forcing) method, the received noise is supposed to be zero or null. The problem of the Gaussian Noise is especially noticeable when the signal to noise ratio (SNR) is low. Communication in a wireless environment is highly unreliable so the Bit Error Rate (BER) of a wireless system is significantly higher as compared to the wireline system. This is just due to the fading nature of a wireless system. It can be limited by using the whole scenario as an optimization problem and applying the conventional convex optimization techniques to control the problem of the increased BER.

5. Conclusion

The collaborative communication of complex networks is very effective in providing the high bandwidth and the higher growth. It obviously imparts the benefits to the wireless service system with its own characteristics and advantages. It should be fully appraised into the account for mastering the complex network cooperative communication up to an acceptable extent. It is the salient model to inspect the collaborative diversity techniques in order to optimize the cooperative communication up to the supreme level. The MIMO complex network communication technology is optimized and analyzed to get the considerable communication capacity and even get more node links across the network in order to strengthen the communication process.

6. References

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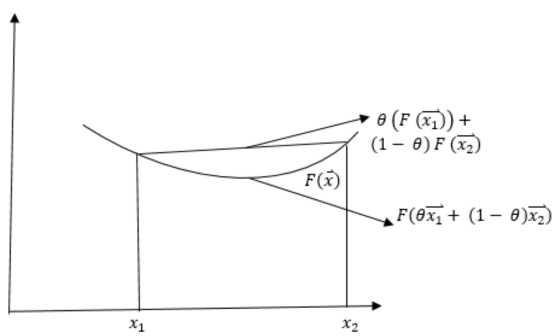
PROOF OF JENSEN's INEQUALITY:

Jensen's inequality is a very handy tool that arises in various scenarios while working in wireless communication systems and signal processing.

1. **JENSEN's Inequality for the Convex Functions:**



For a convex function: -

$$F(\theta\overrightarrow{x_1} + (1-\theta)\overrightarrow{x_2}) \le \theta\left(F(\overrightarrow{x_1})\right) + (1-\theta)F(\overrightarrow{x_2}) \qquad (1)$$

Or,

$$F(\theta_1\overrightarrow{x_1} + \theta_2\overrightarrow{x_2}) \le \theta_1\left(F(\overrightarrow{x_1})\right) + F\,\theta_2(\overrightarrow{x_2})$$

The above equation shows the probability and we can write it like:

$$\theta_1 = P_r\left(X = \overrightarrow{X_1}\right)\, and\, \theta_2 = P_r\left(X = \overrightarrow{X_2}\right)$$

Now,

$$\theta_1\overrightarrow{x_1} + \theta_2\overrightarrow{x_2} = \overrightarrow{X_1}\,.\,(\,P_r\left(X = \overrightarrow{X_1}\right)) + \overrightarrow{X_2}\,.\,P_r\left(X = \overrightarrow{X_2}\right))$$

Since, $\sum_i P_r\left(X = \overrightarrow{X_\iota}\right)\overrightarrow{X_\iota} = E(\{\vec{X}\})$;

This implies, $F(\theta_1\overrightarrow{x_1} + \theta_2\overrightarrow{x_2}) = F\left(E\{\vec{X}\}\right)$ (2)

Now,

$$\theta_1 F(\overrightarrow{x_1}) + \theta_2 F(\overrightarrow{x_2}) = F(\overrightarrow{X_1})(P_r\left(X = \overrightarrow{X_1}\right) + F(\overrightarrow{X_2})(P_r\left(X = \overrightarrow{X_2}\right)$$

This implies,

$$\theta_1 F(\overrightarrow{x_1}) + \theta_2 F(\overrightarrow{x_2}) = E\{F(\vec{x})\} \qquad (3)$$

Putting (2) & (3) in equation (1).

$$\mathrm{F}\{\mathrm{E}(\vec{x})\} \leq E\{F(\vec{x})\} \qquad (4)$$

Equation (4) is known as the Jensen's inequality for the convex functions.