

End to End Latency incurred in Cooperative Communication System

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Abstract— Due to uprising of technology, next generations of cellular communication, such as 5G, are expected to provide enhanced data rate, higher capacity & upgraded performance in contrast to existing cellular standards and generations. For this prospect to turn into genuineness, cooperative communication is proposed for the future generation of mobile communication as an optimization technique. It incorporates cooperation in the system using handy devices such as mobile phones, tablets etc. These devices, that are traditionally single antenna devices or nodes are now allowed to use antennas of the other users in the network, logically making an array of antennas which are connected by a logical mean and offering various gains and performance benefits of spatial diversity to a single antenna user at the lower cost as compare to physical arrangement. However, the network latency and data security are seen as primary hindrances involved in the commercial implementation of cooperative communication systems. In this regard, this article presents comparative analysis of end to end latency in cooperative communication in contrast to conventional approach by considering three different positions of relay.

Keywords— Amplify and Forward (AF); Decode and Forward (DF); Error Control Coding (ECC); Independent and identically distributed (IID); Maximal Ratio Combining (MRC); Relay Station (RS); User Equipment (UE); Universal Mobile Telecommunication System (UMTS)

I. INTRODUCTION

Due to the limited and expensive radio resources, one cannot infinitely increase the network capacity i.e. the availability of vacant bandwidth is not expected to increase significantly. To date, the only way to get around this is by controlling the transmission power and increasing the spatial reuse of frequencies by cell spitting or sectoring. However, these methods incur huge installation and maintenance costs in traditional mobile cellular communication systems. Furthermore, high license fee is an issue; there is thus a threat that high-quality wireless services may soon become an unaffordable luxury.

To address this issue, in recent years, cooperative relaying technologies have also made their way toward next generation wireless standards such as IEEE 802.16 (WiMAX) or LTE advance and have been incorporated into many modern wireless applications such as cognitive radio and secret communications. Several performance gains such as path loss, diversity and spatial multiplexing gain can be achieved by

inducing cooperative communication in a system. This is because cooperative communication in a multi user network enables a single antenna user to share the antennas of other users. This will create a virtual array of antennas at the transmitting side & will not only enable the users to have benefits of diversity & multiple-input multiple-output (MIMO) but also won't demand any additional cost. These benefits yield reduction in transmission power, increment in the system capacity & extension in coverage. From commercial aspects, cooperation among the network nodes will also reduce the cost of development, optimization of BSs & rental costs of their sites [1], [2] & [3]. The performance analysis of cooperative communication protocols is currently the most active research area. These protocols can roughly be classified into two groups that are transparent and regenerative relaying protocols [4]. In transparent relaying Amplify and Forward (AF), Linear-Process and Forward (LF) and Nonlinear-Process and Forward (nLF) are famous. In the case of regenerative relaying protocols, Estimate and Forward (EF), Compress and Forward (CF) and Decode and Forward (DF) are noteworthy [5].

Latency is the vital criteria to judge the performance of any communication systems and has a major impact on user experience. Interactive or any real-time services, for example conversational services, such as VoIP and video telephony, often do not require high data rate but has tight constrain on low latency. It won't be wrong to treat latency as a measure of better service and end user satisfaction. So, low latency means better service and more satisfaction of end user. Therefore, it becomes crucial factor in performance evaluation of any communication system beside power and bandwidth efficiency. Expected latency caused by the cooperation is the major constraint in the commercial implementation of cooperative communication system and fades the gain it offers. That is why this paper provides an estimation of total or end-to-end latency incurred in cooperative communication system so that precise performance of the system can be evaluated.

The paper is structured as follows. System model of cooperative communication and end to end latency is presented in section II. Our contributions to the existing system model are presented in section III. In section IV simulation results are shown and analyzed. Conclusion and future work recommendations are presented in last section.

II. SYSTEM MODEL

The Basic idea of cooperative communication is to cooperate in order to reach the destination in the network rather to contest for the network resources as in conventional networks. Cooperative communication can significantly reduce the fading effects and other channel losses by utilizing cooperative model. For example, when a source node cannot reach the destination due to severe fading, a relay node that has better channel conditions with both this source node and the destination cooperates with it in order to reach the destination. In this cooperative approach, the performance improvement depends upon degree of cooperation [5]. As a matter of fact, wireless medium is broadcast by nature i.e. an EM wave spreads when propagates in the medium. Due to this fact, nodes near to the source hear the transmission and can convey the same to the destination and thus resulting in cooperation in a network [3]. Network nodes in this regard can be seen as a set of antennas that can form virtual arrays by relaying information and hence can obtain the advantages of Multiple Input Multiple Output cheaply [6]. Basic system model of Cooperative communication is illustrated in Fig. 1. This model consists of three nodes i.e. source, relay and destination. However, in practice there may be a multiple relay in between source and destination. Such arrangement is referred to as multi relay model. However, this work is limited to a single relay model.

I. Cooperative communication

Relay communication general have two categorization, fixed or static relaying & adaptive or dynamic relaying. In fixed or static relaying, a relay will always cooperate with source & destination. This scheme has advantages of easy implementation but low bandwidth efficiency or wastage of resources in some cases where source and destination already has good channel conditions and doesn't need any assistance. In adaptive or dynamic relaying, a relay will serves the source & destination on demand i.e. when there is a need of cooperation. This scheme has advantages of complex implementation but good bandwidth efficiency. In this paper we considered a fixed relay case. From transmission perspective relay communication can be modeled as orthogonally and non-orthogonally [7]. In this work orthogonal case is considered in which communication take place in two phases. Firstly, a source node transmit the message to destination and a nearby node that hears the transmission due to broadcast nature of medium relays the information to the same destination in the second phase. A relay may perform some action on message depending upon implemented protocol. For Phase 1, Y_{sr} (signal received at the Relay) and Y_{sd} (signal received at the destination) can be modeled as [8]:

$$Y_{sd} = \sqrt{P}h_{sd}x + n_{sd} \quad (1)$$

$$Y_{sr} = \sqrt{P}h_{sr}x + n_{sr} \quad (2)$$

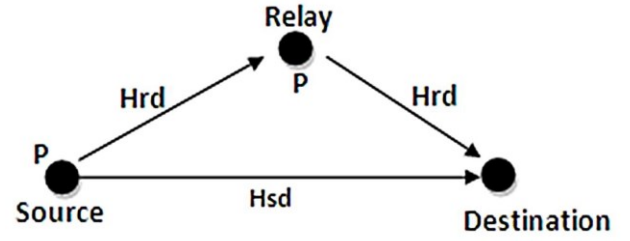


Fig. 1 Simplified cooperation model

In Equation (1) & (2), P denotes the power, x is user data or Information, n_{sd} & n_{sr} are additive noise and h_{sd} & h_{sr} represents random Rayleigh flat fading channels gains. These channel fade and noise are mathematically modeled as Complex Gaussian Random Variable of Zero Mean and Variance " N_0 ". In the second phase, Cooperating node will process the received data according to implemented protocol and resend it to the destination. This can be mathematically written as.

$$Y_{rd} = h_{rd}Q(Y_{sr}) + n_{rd} \quad (3)$$

In Equation (3), $Q(\cdot)$ represents the implemented protocol at the relaying node.

II. End to End latency or Overall Delay

End to end latency is defined as the time taken for a successful transmission of the message from source to destination i.e. the time during which a source node transmits information to a time when it receives an acknowledgement from destination. User satisfaction and experience is heavily relies on latency. Interactive or any real time application and services often do not require or demand high data rate but has tight constrain on latency. Because of such a large influence on user experience latency has become crucial factor in performance evaluation of any communication system in addition to power and bandwidth efficiency. In a non-cooperative network a large separation between source node and destination node is reflecting bad channel conditions and so the worse user experience. This can be overcome by the introduction of a relaying node in the network. But the same will also alter or increases the overall latency of the network. Whether it's a cooperative network or a conventional system, a packet may experience variety of delays during its journey towards the destination. Moreover, the actual latency also depends on the other parameters as well, such as the level of congestion in the network and number of hops or nodes etc. for the estimation of end to end latency or overall delay in a network we consider four types of fundamental delays in our model. Such as Nodal processing delay, which itself includes control plane and user plane latency. Control plane latency is the time required for an exchange of signaling and control information between source and destination prior to the transmission of user data. While transmission time for user data is known as user plane latency. As per technical reports [9] & [10], The International Telecommunication Union (ITU) requirements on C-Plane Latency are within or almost equal to 100ms while U-Plane latency should be kept within 10ms. We will make use of these reports to estimate overall latency involved in LTE based Cooperative system. Another contribution in overall delay is propagation delay which is time

a packet spends in the air while propagating from one node to other. Since we have considered three different position of relay from source and destination so the propagation delay is calculated accordingly. When cooperation in a network is implemented, a cooperating relay will also take some time to process the message to be relayed. It is known as relay processing delay and is solely depends upon implemented protocol, processor of the relay (hardware) and the software that is why it is next to impossible to accurately calculate it. Therefore, this work uses a hypothetical value of it to estimate overall latency incurred by cooperative systems. In terms of queuing delay, in previous proposed models such as [11] and [12], queuing delay is calculated by choosing a fixed (not moving) relay between source and destination. Moreover, no specific relaying protocol is mentioned in the proposed cooperative systems. Therefore, this work can be considered as a modification or an extension to proposed system in [11] & [12] taking account of the queuing delay and considering the two different relaying protocols viz. Amplify and Forward from transparent relaying protocols family and Decode and Forward from the regenerative. In addition to that, the relay position has also been varied in order to integrate the varying propagating conditions for a more realistic system model. Channel or path between any two nodes, be it source-relay or relay-destination or source-destination, has some associated probability such that when a source node (S) with power P transmits a packet, the probability that the receiving or destination node (D) can decode the message or information correctly is given as $P_{s,d}$ i.e. probability of successful delivery can be modeled as [11]:

$$P_{s,d} = P \frac{|h_{s,d}|^2 P}{N_0} > \gamma \quad (4)$$

In Equation (4) $h_{s,d}$ is the channel gain for the channel between source (s) and receiver (d), N_0 is the power density of noise at the receiving node d, while γ is some pre-defined threshold signal to noise ratio (SNR) required for reliable communication. When the transmitting node (source node) is unable to send a message to the destination due to severe channel fading, resources are wasted if the source node continues to attempt to resend. If a third party (in our case a relay) that hears an information message from an information source (due to the broadcast nature) can help it by a channel other than the source to the destination channel, i.e. an independent channel, as shown in Fig. 1. It shows that the probability of success will be higher and this reduces queue delay and improves overall performance. It is clear from the above statement that the probability of successful delivery of nodes near the destination is high. i.e. " $P_{n,n+1} > P_{n-1,n+1} > \dots > P_{1,n+1}$ ".

III. THREE POSITIONS OF RELAY

We have varied relay position with respect to source and destination to capture the effect of relay position on overall delay. This is an important modification in the system model because adding relays in the transmission path will defiantly upraise latency but its position can combat this increment. To demonstrate the importance of relay position and its impact on latency, three different positions of relay has been considered and results have been added in the queuing delay model. These positions are illustrated in Fig.2. In Case 1, when relay is near to

source node, Probability of successful delivery between source and relay (P_{12}) would be higher and whereas probability of successful delivery between relay and destination (P_{23}) would be less because relay is considerably away from destination. This arrangement won't reduce the latency because relay is far from destination and will take some time to reach it.

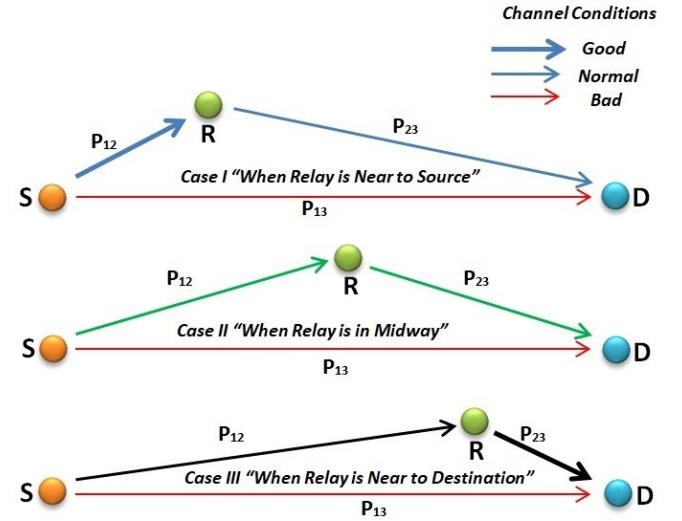


Fig. 2 Three Position case

Now consider a second case when relay is half way to both destination and source. In this case Probability P_{12} and Probability P_{23} have a moderate value because relay in this case is at the middle distance from both source and destination. This position slightly reduced the delay as compare to the first one. Finally in third case, relay is close to destination. In this case Probability P_{12} would be less but Probability P_{23} would be higher because of smaller amount distance between relay and destination as represented by a good Channel Condition. In this case delay is further reduced as compare to other cases.

IV. RESULTS

In order to compare the performance of the proposed model, Matlab simulations are performed for both cooperative and non-cooperative communication systems. For simplicity, BPSK is chosen as a modulation scheme for testing purpose. Channel or medium gains are modeled as single tap Rayleigh flat fading along with additive white Gaussian noise (AWGN). It was further assumed that the relay and destination perfectly knows the channel gains rather channel estimation as in practice.

Firstly result of Queuing delay is shown in Fig. 3. Queuing delay is plotted against arrival rate. In this figure comparison of queuing delay caused by cooperative communication system with three different position of relay with respect to non-cooperative communication system is made. Each position has some associated probability of successful delivery as already discussed earlier. As expected, Fig.3 shows that the queuing delay increases with increase in arrival rate. However, an interesting fact is that the cooperative system has reduced queuing delay as compare to non-cooperative transmission. The reason of this is that when a link between source and destination is in outage for a while, it would not only be a wastage of resources but also expensive to go for re-transmission or attempt

error correction at destination as done in conventional communication systems. Instead, let the another node who also received the transmission due to broadcast nature of medium and has better channel conditions with both destination and the source to transmit the source message to the destination. This approach results in reduced queuing delay and so the system performance is enhanced. Furthermore, relay's position also plays a vital role in reducing this delay. As shown in Fig.3, when the relay is near to destination we have the least queuing delay as compare to other two positions.

After a queuing delay, overall delay is calculated on the basis of system model and assumptions discussed earlier. Overall delay is also plotted against the arrival rate. Fig.4 shows the overall delay due to a single relay operating in FDD mode with Amplify & Forward protocol in contrast to direct transmission. Fig.5 shows the TDD version of the same. Delay in non-cooperative case is expectedly less as compare to cooperative system. Overall delay in non-cooperative system increases rapidly with the increase in arrival rate whereas overall delay in cooperative system is quit steady. Moreover, this delay can be reduced by the position of relaying node. As seen in case 3, when relaying node is near to destination overall delay of cooperative system is very much reduced and approaches near to that of non-cooperative system at higher arrival rate. TDD version has slightly higher delays because of TDD Transmission nature.

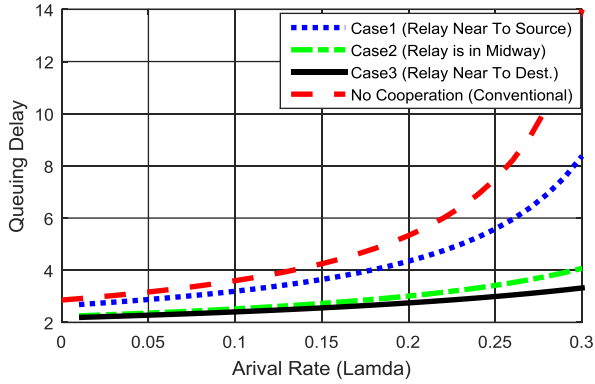


Fig 3. Queuing Delay Matlab Graph

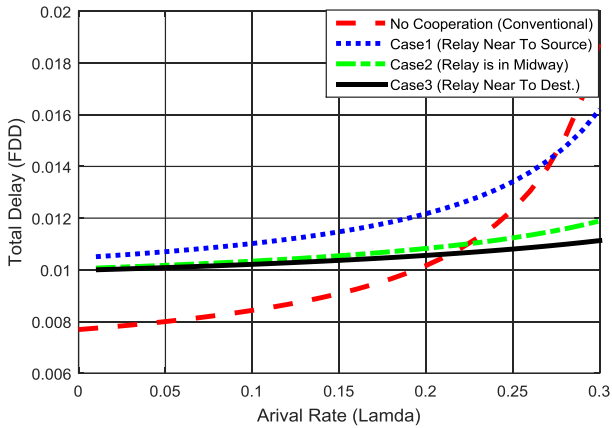


Fig 4. Overall delay –Single Relay With AF – FDD mode

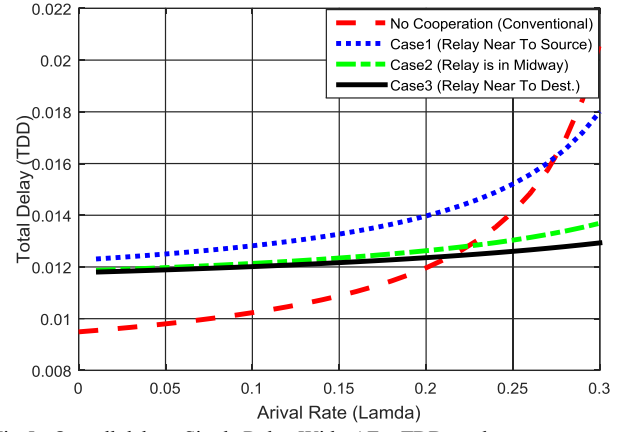


Fig 5. Overall delay –Single Relay With AF – TDD mode

Fig.6 and Fig. 7 shows the overall delay due to a single relay operating in FDD and TDD mode with Decode & Forward protocol in contrast to direct transmission respectively. In previous work proposed by us in [13] & [14], it has been shown that performance wise decode and forward has better results as evidenced from its bit error rate, throughput and outage probability curves over its AF counterpart. However, when it comes to latency, the delay is increased because of encoding and decoding action performed by the DF node.

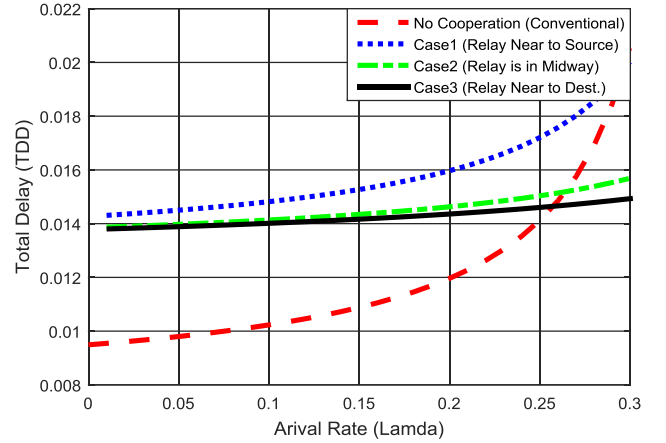


Fig 6. Overall delay –Single Relay With DF – FDD mode

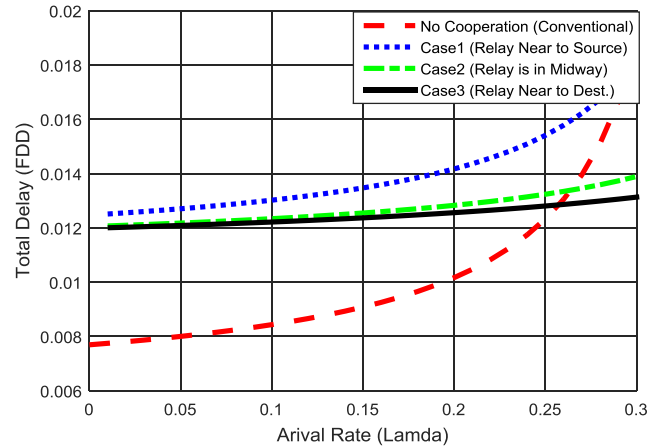


Fig 7. Overall delay –Single Relay With DF – TDD mode

V. CONCLUSION

Low latency is one of the key performance criteria in order to ensure better service and user satisfaction and for cooperative communication latency is one of the major constraints of having less market interest. In this work, we addressed the latency issue in cooperative communication and evaluate that there are many other ways to cope up this issue in order to enjoy the benefits of diversity by reducing the inherent delay utilizing the relay position. Other variations and techniques like relay selection may further reduced the delay.

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