Energy Efficiency of Base Station Cooperation Using Amplify-and-Forward Relay Protocol

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***Abstract*;** Since 80% of energy is consumed in radio access side, advanced deployment strategies such as amplify-and-forward (AF) relay networks were presented to provide special diversity for future mobile communication systems. In this paper, BS cooperation scheme is proposed using AF relay protocol for relatively smaller cells than conventional networks. Here, performance of the proposed scheme outperforms both direct transmission and relay cooperative protocols in such a way that, it consumes lower transmission energy than AF for both source and relay nodes. Furthermore, impacts of distance dependent path loss and log-normal shadowing on the performance of proposed scheme are examined and compared to the available schemes such as AF relay networks. Finally, advantages of using fixed and optimal power allocation for base station cooperation schemes are examined and compared to AF relay cooperative networks. It was observed that BS cooperation scheme results in almost 67.64% reduction in μjoules/bit, for both uplink and downlink modes at the worst case. Hence, less power will be consumed to combat fast variations in channel conditions such as log-normal shadowing effect.

Keywords— Amplify-and-forward (AF), Base Station cooperation, Cooperative diversity, Inter Site Distance (ISD).

1 INTRODUCTION

From the last few years, cellular networks have been growing at an unprecedented rate. Nearly six billion mobile subscribers exist globally which implicate the fact that mobile communication has been nearly used by every person on the planet. This makes the network to consume a huge amount of energy to satisfy subscriber requirements [1]. Increasing energy efficiency is the major interest of cellular network operators for both economic and environmental reasons [2]. Recent survey identified that 80% of the energy is consumed in the radio access side of the cellular networks, particularly at the base stations (BSs). Taking LTE network as an example, the survey verified that the energy efficiency of LTE systems over a large geographic area appears to be very poor [1]. Therefore, a reliable transmission with effective data-rate seems to be very difficult due to multipath fading, shadowing and path loss effects. These effects are random variation in channel conditions in time, frequency and space which makes it consume more energy to combat the channel conditions in a wireless environment.

Basically, there are two ways for optimizing the energy consumption in the BSs. Firstly, optimizing every single BS by using high quality software and power sensitive hardware. Secondly, professional deployment strategies have to be developed at radio access side to increase the energy efficiency of the system. In addition to that, it is widely believed that using small cell with low power base stations improve energy efficiency compared to the high power BS in large cells [2]. Moreover, the power consumed in different components of the BS varies depending on the characteristics of the components. Therefore, energy saving in a specific component consequently results in energy saving of the overall system level [1]. In the recent years, people have been developed different deployment strategies to combat channel conditions and to increase energy efficiency of the communication systems.

Transmit and/or receive diversity can be achieved when uncorrelated channel exists between sources and destinations and combining them in such a way that the effects of path loss are reduced. Diversity combining is the most powerful technique that reduces the probability of signal experiencing deep fade simultaneously [3]. Recently, to improve energy efficiency of the cellular network at the radio access side, cooperative communication is proposed. It uses multiple-input multiple-output (MIMO) scheme that enables an antenna to act as a multiple antennas virtually in transmission of mobile phone and BSs [4]. The advantage of MIMO systems is to provide transmit and/or receive diversity in such a way to reduce energy consumption with effective quality of services. In order to achieve this, the antennas have to be positioned apart from each other in order to obtain multiple independent paths.

However, MIMO systems are costly and the size of antennas is limited for different applications; for example, in sensor networks or cellular phones, it might not be practical to place multiple antennas in single equipment. For this reason, an alternative way is proposed to achieve a distributed antenna system by cooperating multiple nodes with each other. Relaying is a very popular and cost-effective transmission technique in which the nodes cooperate with each other in order to maximize the Signal to Noise Ratio (SNR) at the receiver. There are two most common relaying protocols; namely, non-regenerative (also known as AF) and regenerative (also known as Decode-and-Forward). AF is simpler and is easier to implement, because unlike decode-and-forward, relay does not need to perform decoding. We do not consider Decode-and-Forward in this paper whereas AF is utilized for the base station cooperation.

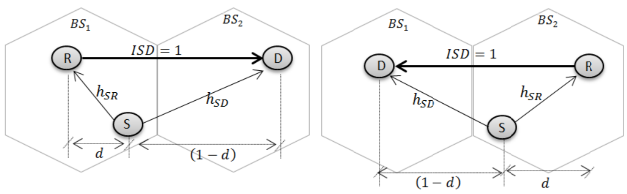
Since, this work has not been done previously, it motivate us to apply the proposed scheme on AF relay networks. Although, some researches carried out about BS cooperation, we use the principle of AF cooperative relay network for the purpose of this paper. The main motivation of this work is to propose a novel scheme in order to improve the energy efficiency of the system by applying the principles of AF relay networks on two neighbouring BSs. The main idea behind using BS cooperation is that, mobile station (MS) may not have a clear line of site with the served BS; in this case, it experiences lognormal shadowing. On the other hand, it might have a clear line of site with another BS in the neighbouring cells. Considering the abovementioned scenario, the main contributions of this paper are;

- A new scheme of BS cooperation is proposed using the principles of AF cooperative relay networks.
- Bit error rate (BER) of the proposed scheme is analysed and optimal power allocation factor is obtained using Monte-Carlo simulations.
- It is shown that the proposed scheme resists large variations due to log-normal shadowing and thus overall improves the energy efficiency of the cellular systems.

The remainder of this paper is organized as follows. In section II, the proposed system scenario is shown for BS cooperation. System model and equation modification for the system scenario are presented in section III. In section IV, some simulation results are analysed. Finally, section V concludes the paper.

2 System Model:

The system scenario for the proposed scheme of BS cooperation is slightly similar to that of AF relay network. Basically, the scenario is that the served BS relays the signal and forwards to the adjacent BS (Destination). Hence, the direct link between the MS (Source) and the next cell's BS is also available to provide the spatial diversity. In uplink mode, the Destination BS receives the signal from both MS and the relayed link from the Relay BS as shown in fig. 1.

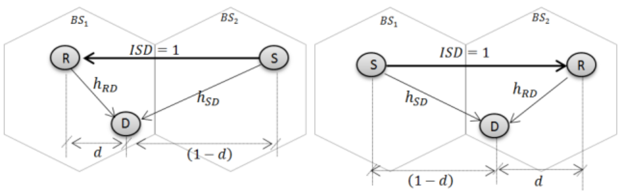


(a) (b)

Figure 1: Uplink system Model. **(a)** MS served by BS1. **(b)** MS served by BS2.

Now in downlink mode, the MS (Destination) receives the signal from both links; direct link form adjacent BS and relayed link from the served BS as shown in fig. 2.

Since, the theoretical power model is used (i.e., circuit power is neglected) only uplink model is expressed here which is identical to downlink mode. Similar to AF, the current time slot has to be divided in to two sub-slots using



(a) (b)

time division. Moreover, the Inter Side Distance (ISD) between the two BSs is normalized to one, and the MS moves on a straight line along the ISD. In addition, a high speed loss-less link is available between relay-destination for uplink mode and source-relay in downlink mode as shown in Fig. 1 and Fig. 2.

Figure 2: Downlink system Model. **(a)** MS served by BS1. **(b)** MS served by BS2.

In both cases (a and b), the source (MS) transmits information in first sub-slot and stops transmitting in the second sub-slot. Then the signal is received by both relay and destination nodes simultaneously assuming perfect synchronization. In phase II, the relay amplifies the received signal before retransmitting to the destination. Similar to cooperative relay networks, two links are available between source and destination; direct link and relay link. Therefore, the signal detection and diversity combining is performed by the destination.

3 Bit Error Rate Analysis

The direct link between source and destination can be assumed as a direct transmission from source to destination. This direct link is affected by Rayleigh fading as well as distance dependent path loss. The received signal at destination, received SNR and BER performance are derived as in the literature, and they have been modified here to represent the current system [5].

$$y_{SD}(t) = \sqrt{P_s.(1-d)^{-a}}\; h_{SD}\, s(t) + n(t) \quad (1)$$

$$\gamma_D = \frac{P_s\ (1-d)^{-a}\ |h_{SD}|^2}{N_o} \quad (2)$$

where $s(t)$ is the transmitted signal at the source with transmit power of P_s, $y_{SD}(t)$is the received signal at the destination, h_{SD} is flat Rayleigh fading channel between source to destination, $n(t)$ is noise power with one sided power spectral density of N_o, $(1-d)^{-a}$ is small scale path loss, whith a is path loss exponent, d is the distance from source to relay and $\gamma_D$is the direct link instantaneous SNR at the destination, respectively.

In this model, the wireless part of the relay link is affected by the multipath Rayleigh fading and the distance dependent path loss. In addition, it is assumed that log-normal shadowing effect exists between MS and served BS. Therefore, the received signal and SNR can be expressed similar to that mentioned earlier [5].

$$y_{SR}(t) = \sqrt{P_s\ \ PL^{-1}}\ \ h_{SR}\, s(t) + n(t) \quad (3)$$

$$\gamma_{SR} = \frac{P_s\, PL^{-1}\, |h_{SR}|^2}{N_o} \quad (4)$$

$$PL(d) = d^a * 10^{X_\sigma/10} \qquad (5)$$

where PL is the path loss contributions which is a combination of distance dependent path loss (d^a) and log normal shadowing fading (X_σ).

The relay BS amplifies the received signal by a factor of (G) and forwards to the destination BS. Depending on the assumptions that have been made earlier; a lossless link backbone network connects various BSs to a central processing unit [6]. Hence, the signal in the backbone network is not affected by shadowing and Rayleigh fading, or the distance dependent path loss might be extremely small which can be ignored (i.e., it can be modeled as AWGN channel). Hence, the received power at the destination BS is similar to that in [5]

$$y_{RD}(t) = \sqrt{P_r}\ G\ y_{SR}(t) + n_2(t) \qquad (6)$$

$$y_{RD}(t) = \sqrt{P_r}\ G\ \left[\sqrt{P_s\ PL^{-1}}\ \ h_{SR}\, s(t) + n_1(t)\right] + n_2(t)$$
$$= \sqrt{P_s\, P_r\ PL^{-1}}\ G\ h_{SR}\, s(t) + \sqrt{P_r}\ \ G\ n_1(t) + n_2(t) \qquad (7)$$

where P_r is transmitted power of relay node, and y_{SR}, y_{RD} are the received signals at both relay and destination nodes, respectively. Moreover, n_2 is the AWGN noise with one-sided power spectral density of N_o.

The destination receives the signal that has been sent by the relay (its neighbor BS via high speed loos less link) and is an AWGN channel. Therefore, the received SNR for the relay link can be derived similar to AF relay network [5].

$$SNR = \frac{P_s\ P_r\ PL^{-1}\, G^2\, |h_{SR}|^2}{P_r\ G^2\ N_o + N_o} = \frac{\frac{P_s\ PL^{-1}\ |h_{SR}|^2}{N_o} \cdot \frac{P_r}{N_o}}{\frac{P_r}{N_o} + \frac{1}{G^2\ N_o}}$$
$$= \frac{\gamma_R\, \gamma_D}{\gamma_R + \gamma_D} \qquad (8)$$

where $\gamma_R = P_s\ PL^{-1}|h_{SR}|^2/N_o$ and $\gamma_D = P_r\,/N_o$ are the instantaneous received SNRs at the relay and destination respectively. Similar to the relay network, the instantaneous amplification factor can be expressed as [5]

$$G^2 = \frac{1}{P_s\ PL^{-1}|h_{SR}|^2} \qquad (9)$$

Since the relay link is a combination between two different channels; wireless channel from source to relay and AWGN channel from relay to destination, the average bit error rate (BER) of the relay link can be found approximately by adding the two BERs of the different channels as in [7].

$$\mathrm{BER}_{Relay} \approx \mathrm{BER}_W + \mathrm{BER}_{AWGN} \qquad (10)$$

where BER_{Relay}, BER_W and BER_{AWGN} are the BERs for Relay link, wireless channel and lossless link, respectively. For both uplink and downlink system models, the MRC combining techniques are slightly similar. However, the combining technique needs to be placed in BSs for uplink mode, and similarly in mobile terminals for downlink mode. From system model that has been shown earlier for both uplink and downlink scenarios, two links are available between source and destination; direct link and relay link.

To maximize the equivalent SNR at the combiner, the weights are chosen in [8], [9] and [10] as follow

$$w_1 = \alpha_{SD}^* \quad ; \quad w_2 = \frac{\alpha_{SR}^*\ \ G^*\ \ \alpha_{RD}^*}{G^2\ |\alpha_{RD}|^2\ + 1}$$

Therefore, the signal at the output of the combiner can be expressed as

$$y_{MRC} = \alpha_{SD}^*\ y_{SD} + \frac{\alpha_{SR}^*\ G^*\ \alpha_{RD}^*}{|G|^2\ |\alpha_{RD}|^2\ + 1}\ y_{RD} \qquad (11)$$

where ($\alpha_{SR}^* = \sqrt{P_s\ PL^{-1}}\, h_{SR}^*$ and $\alpha_{RD}^* = \sqrt{P_r}$ for uplink mode, and similarly, $\alpha_{SR}^* = \sqrt{P_s}$ and $\alpha_{RD}^* = \sqrt{P_r\, PL^{-1}}\, h_{RD}^*$ for downlink mode) are the complex conjugate of the attenuation contributions of source-relay and relay-destination links, respectively, and ($\alpha_{SD}^* = \sqrt{P_s\ (1-d)^{-\alpha}}\ h_{SD}^*$) is the complex conjugate of attenuation contributions of the direct link for both uplink and downlink scenarios. Since, assuming that γ_{SD} is the direct link SNR, the overall equivalent SNR can be expressed as in [5]

$$\gamma_{eq} = \gamma_{SD} + \frac{\gamma_R\, \gamma_D}{\gamma_R + \gamma_D} \qquad (12)$$

The overall BER for a cooperative relay network that is defined in [11] cannot be applied here for this model. Therefore, a closed-form expression for the BER is not mathematically tractable.

4 SIMULATION ANALYSIS

In this section, the performance of the proposed system is evaluated by comparing the simulation results to the performance of AF relay networks. To examine the performance of the proposed scheme, different parameters are used for simulation setup in MATLAB software. The common parameters for system configuration are summarized in the table below.

Table I: summarized system setup parameters.

Parameters	**Values/Explanation**
Information data	10e6 equal probability values of 0 and 1
Modulation scheme	Binary Phase Shift Keying (BPSK)
AWGN Channel	Complex Gaussian random variable with zero mean and variance of $N_0/2$
Small Scale Fading	Rayleigh Fading
Log-normal Shadowing Fading	Zero mean Gaussian random variable, average of 10e5 realization is used
ISD	Normalized to 1
Path loss exponent	3 for urban area
Path loss exponent	Single sided PSD is chosen to be 1 and equal for all links

As it mentioned earlier, mobile signals may not have a clear line of site to the served BS, in this case, it experiences lognormal shadowing effect.

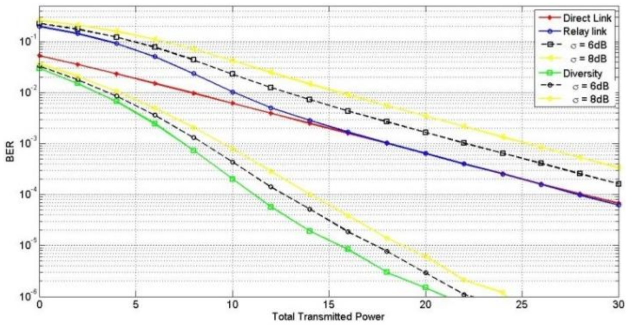


Figure 3: BS cooperation performance mode with Log-normal shadowing effect.

On the other hand, it may have a clear line of site with another BS in the neighbouring cells. In Fig. 3, the performance of BS cooperation is examined with the existence of a lognormal shadowing between MS and served BS. The importance of diversity in cooperative communications can be clearly noticed here, since, it slightly reduces the effects of different levels of lognormal shadowing effect to a smaller variations that can be taken in to consideration (i.e. standard deviations of σ = 6 dB and 8 dB on relay link).

Fig. 4 shows the effect of distance dependent path loss and shadowing effect on the performance of BS cooperation. In this case, total transmission power used to transmit information bit is 11 dB which is less than AF relay networks by more than 8 dB. Moreover, equal transmission power is assumed for both source and relay. The ISD between the two BSs is normalized to one in such a way that BS_1 located at zero position and BS_2 is located at point one, and the mobile moves form BS_1 on a straight line towards BS_2.

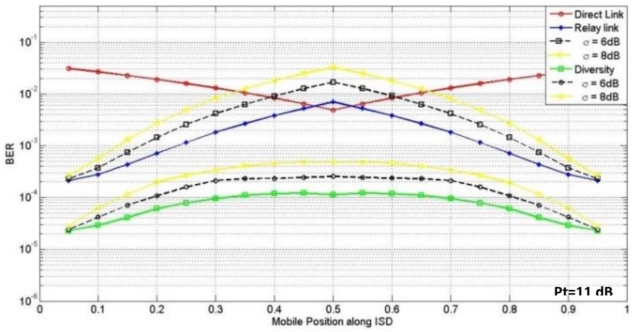


Figure 4: The effect of distance dependent path loss and Log-normal shadowing on BS cooperation systems.

It can be seen that, BS cooperation increases contour availability in such a way that MS always has a high SNR level at the edge of the cell. In addition to that, BS cooperation reduces the effect of fading and lognormal shadowing using less amount of energy. Since, log-normal shadowing is assumed as a slow fading effect [12], two levels of shadowing is used to examine the effect of both distance dependent path loss as well as shadowing effect on BS cooperation. Two levels of log-normal shadowing (i.e., standard deviation σ = 6 dB and 8 dB) are assumed between MS and served BS. Although, various channel affects exits along the relay link, the performance of BS cooperation still acceptable as it reduces the effect of log-normal shadowing.

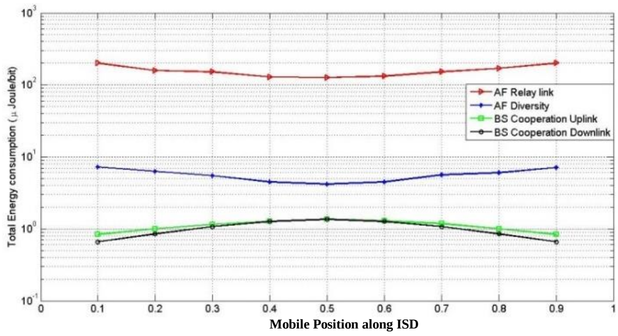


Figure 5: Total Energy consumption with optimum power allocation.

It is shown in Fig. 5 that by using optimal power allocation factor, the energy efficiency of BS cooperation systems is improved considerably. In order to generate more realistic results, a bandwidth of 10 MHz was assumed to get the total energy consumption per bit. In this graph, optimal power allocation is used to achieve the desired BER of 10^{-4}, the graph is plotted in term of minimum transmission energy per bit versus the position of MS along ISD.

It is evident that, using BS cooperation scheme for both uplink and downlink modes has better performance in term of energy saving for cellular system where a significant gap exists between the proposed scheme and both AF relay with and without diversity. A remarkable advantage is achieved using BS cooperation, where it results in at-least 67.64% reductions in μ joules/bit as compared to that in relay cooperative networks.

5 CONCLUSION

In current cellular systems, MS may not have a clear line of site with the served BS, in this case, it experiences lognormal shadowing effects. However, MS may have a clear line of site with another BS in the neighboring cells. For this reason a novel scheme developed here to decrease the impacts of shadowing and to improve the energy efficiency of cellular systems. Ignoring the circuit power, the performance of the proposed scheme for both uplink and downlink is slightly similar. Consequently, although there are large variations of shadowing effects, the proposed scheme of BS cooperation increases energy efficiency of cellular systems remarkably compared to the conventional AF relay cooperative networks. Moreover, the proposed system of BS cooperation may reduce inter-cell interference which requires a high speed backhaul network to link the neighboring BSs in a proper way.

Moreover, advantages of using fixed and optimal allocation factor are emphasized for both uplink and downlink scenarios. It is concluded that, a remarkable improvement on energy efficiency can be achieved for both uplink and downlink scenarios by using optimal power allocation for transmission, where BS cooperation scheme results in 67.64% reduction in μ joules/bit at the worst case as compared to that in relay cooperative networks. However, adding transceiver circuit energy at the BSs for the current results may not degrade the performance of the proposed system, since, a large gap is available between energy saving of the proposed scheme and any other available schemes.

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