Performance Enhancement of LTE-A, a Multi-Hop Relay Node, by Employing Half-Duplex Mode

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Abstract

Relay stations are usually used to improve the signal strength for users near a cell edge, thus extending cell coverage. This paper proposes a study on the performance of a multi-hop relay network. This work introduces half-duplex relay with two scenarios. The first scenario is that wherein the relay node (RN) acts to amplify and forward (AF) and decode and forward (DF), where the relay and user equipment (UE) are fixed. The second scenario is that wherein the proposed UE moves with angular velocity around RN, whereas RN moves with horizontal velocity toward the base station (BS) and UE. The performance measures of each scenario are represented, where the impact velocity on the latency time and system capacity is explained. Both simulation and analytical calculations are provided.

Keywords***:** *LTE, AF, DF, HDX, Relay node***.**

1. Introduction

The 3GPP long-term evolution (LTE) is a new standard developed by 3GPP to address the increasing speed rate and throughput requirements. LTE is the next step in the evolution of 2G and 3G systems and also in the supply of quality levels similar to those of current wired networks. LTE-advanced (LTE-A) is the enhanced version of LTE that aims to further enhance LTE requirements in terms of throughput and coverage. Relay is one of the key technologies considered in LTE-A, which aims specifically to enhance the cell-edge throughput and allow more efficient usage of network resources [1]. In 3GPP LTE-A, relay technologies have been considered and studied actively. A more intense infrastructure can be achieved by spreading relay nodes in such a manner so as to minimize the transmitter-to-receiver distance, thereby allowing higher data rates. Capacity and coverage at the cell edge remain relatively small due to the low signal-to-noise ratio (SNR). Other advantages of relaying in cellular networks are the provision of high data rate coverage in highly shadowed environments (e.g., indoors) and hotspots, reduction of deployment costs of cellular networks, extension of battery lifetime for the UE saving power by reducing the overall transmission power of cellular networks, and improvement of effective throughput and cell capacity [2]. The relay receives and retransmits the signals between base stations and mobile devices to increase throughput and extend coverage of cellular networks. The relays connect wirelessly to base stations; thus, the network offers savings in operators' costs. The basic idea of relay is that instead of BS sending signals directly to the user equipment, the signals are passed between one or more intermediate nodes. Relay stations are usually used to enhance the signal strength for the users near a cell edge, and they can operate in half-duplex mode (i.e., they do not transmit and receive simultaneously in the same band) or in full-duplex mode. Wireless connection on the mobile relay station (RS) is an important mode of communication in future wireless communication systems [2].

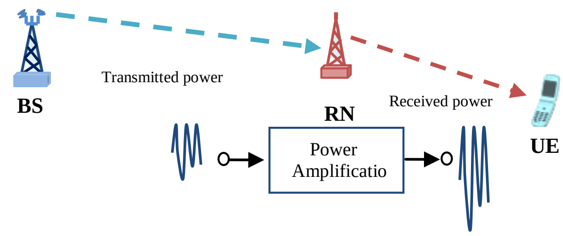
This paper is organized as follows. Section 2 describes the types of relay transmission schemes. Section 3 presents the proposed system model with numerical equations for fixed and moving nodes. Section 4 discusses the results of the proposed model, and the conclusions are presented in Section 5.

2. Relay Transmission Schemes

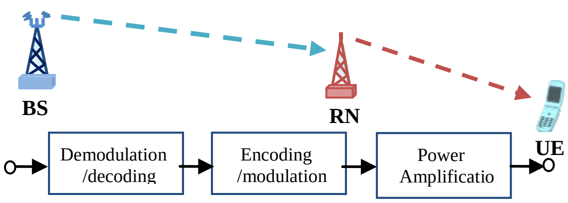
The two-hop communication between BS and UE units through RN can be instituted by different relay transmission schemes. The relay can be categorized in two types depending on its function.

Amplify and Forward (AF): This type simply works as a repeater, where RN receives the signal from BS (or UE), amplifies this signal, and forwards it to UE (or BS). AF relays, although simple and have short delays, are beneficial in most noise-limited system deployments as they amplify both interference and noise along with the desired signal, as shown in Fig. (1-a) [1].

Decode and forward (DF): DF relays detect the desired signal, encodes the signal, and forwards the new signal [3]. Although the processing delay is quite long, DF relays are employed in interference-limited environments where the process results in this class of relays do not amplify noise and interference, as is the case with the AF relay shown in Fig. (1-b). In this paper, we propose a half-duplex for two relay types with two scenarios: (1) downlink data for (AF and DF) relays where RN and UE are fixed and (2) examine the down linked data with mobile RN and circular movement for UE.



(a) AF relay



(b) DF relay

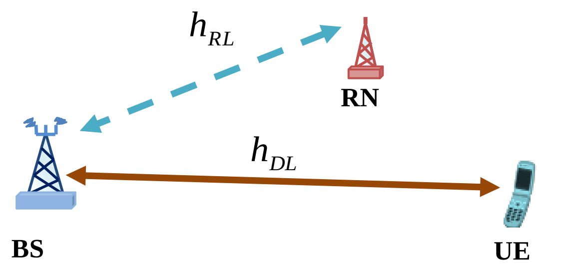
Fig. (1) Types of relay nodes

3. System model

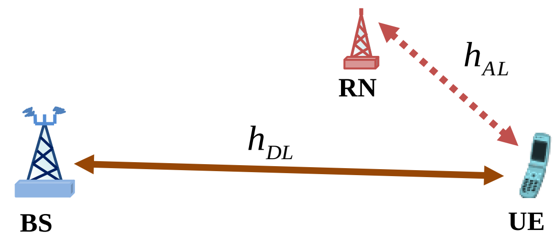
We consider a conjunct system with three wireless nodes, namely, a source base station (BS), a relay node (RN), and a user equipment (UE), as shown in Fig. (2), with the received signal at UE.

$$y = hx + n \qquad (1)$$

where x is the transmitted symbol from BS, h represents the coefficient channel between the source and the destination, and n is the circularly symmetric additive white Gaussian noise (AWGN) in the corresponding channels with variance σ [i.e., n ~ $\mathcal{CN}(0,\sigma)$] [4,7].



(a) Slot one t_1



(b) Slot one t_2

Fig. (2) Half-duplex Relay

3.1 Fixed node scheme

In the first scenario, we suggest that RN and UE are fixed, whereas the suggested system is considered half duplex when the relay cannot transmit and receive simultaneously. In slot $[t_1]$, BS broadcasts its information to both UE and RN. The received signals $y_{RN}[t_1]$ and $y_{UE}[t_1]$ at the relay and their destinations can be written as follows:

$$y_{RN}[t_1] = h_{RL}x[t_1] + n_{RN}[t_1] \qquad (2)$$

$$y_{UE}[t_1] = h_{DL}x[t_1] + n\,[t_1] \qquad (3)$$

At the second slot $[t_2]$, BS sends a signal $x\,[t_2]$, and RN breaks the receiving process but transmits $x_{RN}[t_2]$. The received signal with the time slot $[t_2]$ at UE is referred to in the following equations:

$$y_{UE}[t_2] = h_{DL}x[t_2] + h_{AL}x_{RN}[t_2] + n\,[t_2] \qquad (4)$$

$$x_{RN}[t_2] = g_{AF}\,y_{RN}[t_1] \qquad (5)$$

For a simple AF relay, the forward signal can be assumed as a fixed-gain amplification of the BS original transmit signal (with and without noise), as shown in the equation below, where g_{AF} is the fixed gain scalar, considering the power level of RN [7, 8].

$$g_{AF} = \sqrt{\frac{P_{RN}}{P_{BS}\,|h_{RL}|^2 + \sigma_{RN}{}^2}}$$

P_{BS} and P_{RN} are the transmitted powers from the BS and the relay, respectively, whereas σ_{RN} represents the variance of the relay noises.

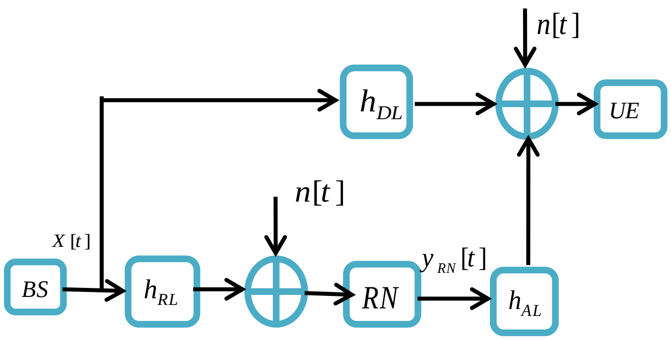


Fig. (3) The general Gaussian relay channel model in the context of the downlink transmission in an RN-assisted cellular network

In this paper, we adopt the system model presented in Fig. (3), where the relay in this model is carried out with a slow and flat fading radio. Subsequently, the channel gains and noises should be unaltered from both time slots $[t_1]$ and $[t_2]$. For UE, we can designate the received signal at UE as the downlink from a system of linear equations as the matrix form:

$$\underbrace{\begin{bmatrix} y_{UE}[t_1] \\ y_{UE}[t_2] \end{bmatrix}}_{\mathrm{y_{UE}}} = \underbrace{\begin{bmatrix} h_{DL} & 0 \\ h_{DL}\,g_{AF}\,h_{RL} & h_{DL} \end{bmatrix}}_{H} \begin{bmatrix} x[t_1] \\ x[t_2] \end{bmatrix} + \underbrace{\begin{bmatrix} n \\ h_{AL}\,g_{AF}\,n_R \end{bmatrix}}_{n}$$

The mutual information of HDX AF-relaying is in the following expression [9]:

$$I_{AF} = \frac{1}{2}\log_2 \det\left(I + \frac{1}{\sigma^2} HH^* \right) \qquad (6)$$

where H is the channel matrix , I that represents the identity matrix.

In the DF transmission, the appropriate channel model is shown in Equations (2), (3), and (4). The source terminal transmits its information as x[t], whereas the relay processes by decoding an estimate of the source-transmitted signal. Under a repetition-coded scheme, the relay transmits the signal [5].

$$x_{RN}[t] = \hat{x}[t] \qquad (7)$$

A relay may fully decode based on a variety of decoding forms, such as the estimate without error and the entire source code word, or a relay may employ symbol-by-symbol decoding and allow the destination to perform full decoding. These options allow trading off of performance and complexity at the relay terminal, because the noise is canceled during the decoding process and the gain is $g_{DF} = \sqrt{(P_{RN} / P_{BS}}$, with the received signal at RN as

$$x_{RN}[t_2] = g_{DF}\,x[t_1] \qquad (8)$$

where the denominator signifies the useful signal power without noises at RN

$$\underbrace{\begin{bmatrix} y_{UE}[t_1] \\ y_{UE}[t_2] \end{bmatrix}}_{\mathrm{y_{UE}}} = \underbrace{\begin{bmatrix} h_{DL} & 0 \\ h_{DL}\,g_{AF}\,h_{RL} & h_{DL} \end{bmatrix}}_{H} \begin{bmatrix} x[t_1] \\ x[t_2] \end{bmatrix} + \underbrace{\begin{bmatrix} n \\ n \end{bmatrix}}_{n}$$

$$I_{DF} = \frac{1}{2}\log_2 \det\left(I + \frac{1}{\sigma^2} HH^* \right) \qquad (9)$$

3.2 Mobility node scheme

In the second scenario, we suggest a new type of movement between UE and the intermediate RN, where UE moves with angular velocity (v_{RN-UE}) around RN, with the radius $^{n}d_{RN}$ that represents an access link. The distance between BS and UE (d_{UE}) is the direct link that changes with the movement of UE. Moreover, the moving relay node (MRN) moves with horizontal velocity between two points (A and B), where d_{BS} is the distance between BS and RN as illustrated in Fig. (4).

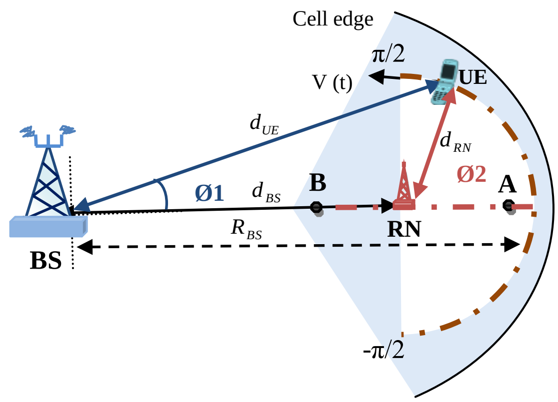


Fig. (4) Architecture of the second scenario with distances between hops

Throughput is affected by the channel environment, such as the distance between the transmitter and the receiver and the fading state of the channel [1]. The channel coefficients between the source i = BS or RN and destination j = RN or UE can be written as:

$$h_{ij} = G(d_{ij})^{-\alpha} \qquad (10)$$

where $G = G_t G_r h_t^2 h_r^2$, G_t (h_t), and G_r (h_r) are the gains (heights) of the transmitter and the receiver antenna, respectively, d is the distance between the source, and destination α (typically $\in \{2-5\}$) is the path-loss exponent dependent on the environment [1, 10].

The velocity of UE around RN can be written as:

$$v_{RN\text{-}UE} = d_{RN} \bullet \frac{\Delta\phi_2}{\Delta t} \quad \ldots (11)$$

The velocity of UE toward BS can be expressed as:

$$v_{\text{BS-UE}} = d_{UE} \bullet \frac{\Delta\phi_1}{\Delta t} \qquad (12)$$

The velocity of RN toward BS can be written as:

$$v_{\text{BS-RN}} = \frac{(A-B)}{t_{\text{BS-RN}}} \qquad (13)$$

$$-\frac{\pi}{2} \le \phi_2 \le \frac{\pi}{2}$$

where $t_{\text{BS-RN}}$ is the RN driving time from RN to BS.

$$d_{RN} = \sqrt{d_{BS}^{\ 2} + d_{UE}^{\ 2} + 2 d_{BS} d_{UE} \cos(\phi_1)}$$

and $d_{RN} \le R_{RN}$, $d_{BS} \le R_{BS}$

where R_{BS} and R_{RN} are the maximum coverage radii for BS and the relay.

We can rewrite Equations (2), (3), and (4) with this scenario as:

$$y_{RN}[t_1] = G_1 (v_{BS-RN} T_{BS,RN})^{-\alpha} x[t_1] + n_{RN}[t_1] \qquad (14)$$

$$y_{UE}[t_1] = G_2 (v_{BS-UE} T_{BS,UE})^{-\alpha} x[t_1] + n_{UE}[t_1] \qquad (15)$$

At the second slot,

$$y_{UE}[t_2] = G_2 (v_{BS-UE} T_{BS,UE})^{-\alpha} x[t_2] + G_2 (v_{RN-UE} T_{RN,UE})^{-\alpha} x_{RN}[t_2] + n_{UE}[t_2] \qquad (16)$$

$$x_{RN}[t_2] = g_{AF}\, y_{RN}[t_1]$$

With the received SNR (ρ) between the source a = BS, RN, and destination b =RN, UE can be written as:

$$\rho_{ab} = \frac{|h_{ab}|^2 P_a}{\sigma_b B} \qquad (17)$$

The half-duplex constraint affects the multi-hop gain, such that if $\rho_{RL} \gg \rho_{DL}$ and $\rho_{AL} \gg \rho_{DL}$ [11], the relay will have more and better antennas to achieve diversity and directional gains. The capacity with DF relay then becomes:

$$C_{DF} = \frac{B}{2} \min\{\log_2(1 + 2(\frac{|G_1 (v_{RN-UE} T_{RN-UE})^{-\alpha}|^2 P_{RN}}{\sigma_{RN} B}), \log_2(1 + 2(\frac{|G_2 (v_{BS-RN} T_{BS-RN})^{-\alpha}|^2 P_{BS}}{\sigma_{UE} B})\} \qquad (19)$$

4. Results

In this section, we conduct simulations to compare the achievable capacities of relaying in two different configurations for half-duplex: AF and DF. Table 1 presents the details of the simulation parameters [2, 12].

Table 1 Simulation Parameters

Carrier Frequency	2G
Bandwidth	20 M
Number of BS	1
Antenna height of BS	25 (m)
Antenna gain	14 dBi
Maximum total transmitting power of BS	46 dBm
Number of RN	1
Antenna height of RN	3 m (above the train or the bus)
Maximum transmitting power of RN	30 dBm
RN-UE antenna gain	5 dBi
RN-BS antenna gain	7 dBi
Number of UE	1
Antenna height of UE	1.5 m
Antenna gain	0 dBm

For the first and second scenario, Figures (5) and (6) show SNR versus the capacity of the backhaul link (RL Link) and access link (AL), respectively. Simulation results exhibit that SNR for the DF relay is better than the AF relay. Figure (7) shows the increase in capacity of the backhaul link with increasing transmitting power for BS. For the second scenario, UE moves with regular velocity around RN, whereas RN moves with horizontal regular velocity toward BS. Figure (8) illustrates the varied capacity with the UE velocity at different latency times. The three results for 5, 10, and 20 ms identify 5 ms latency as the best compared with 10 and 20 ms.

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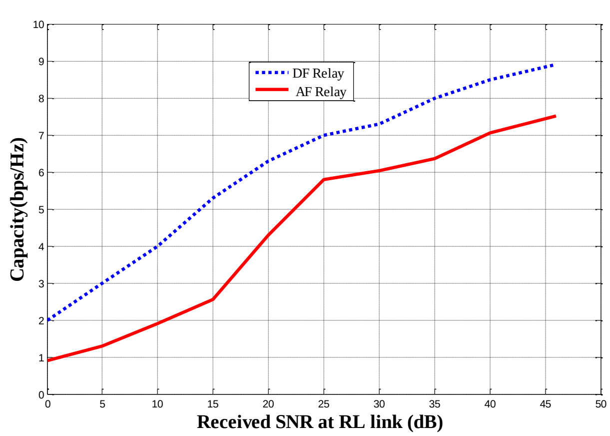

Fig. (5) Capacity versus received SNR of the Relay Link with half-duplex AF and DF Relays

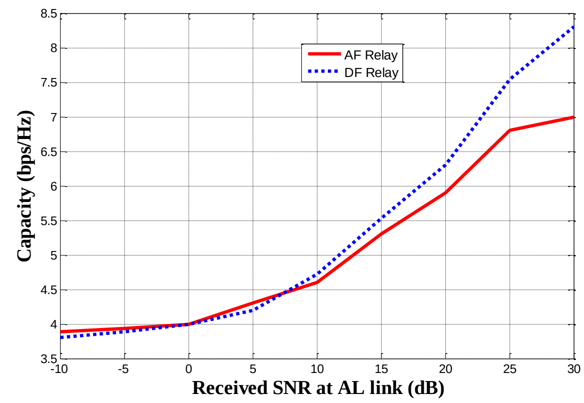

Fig. (6) Capacity versus received SNR of Access Link with half-duplex AF and DF Relays

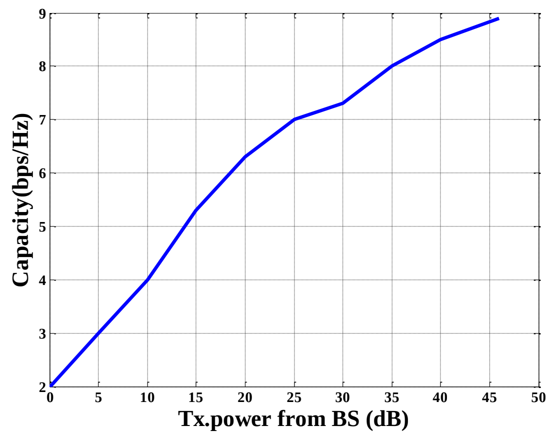

Fig. (7) Capacity versus P_{BS} in the downlink transmission

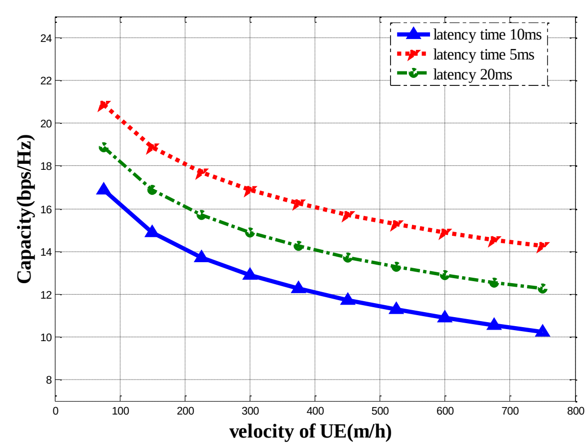

Fig. (8) Capacity versus UE velocity at different latency times

5. Conclusions

This paper introduced two scenarios on the performance of RN and UE in two types of half-duplex relays.

In the first scenario, all nodes (BS, RN, and UE) were fixed with AF and DF relays, whereas in the second scenario, UE was moving with angular velocity around RN, whereas RN was moving with horizontal velocity toward BS and UE, taking the path loss and fading in the account.

Therefore, DF relay improved SNR better than AF relay. This paper explained the impact of the velocity of user capacity. This paper also described the relationship between velocity and capacity with different latencies with respect to distance between the source and the destination.

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