UTILIZATION OF RELAY NODE IN LTE NETWORK CELLULAR SYSTEMS

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Abstract

Relaying is one of the features being suggested for the 4 G LTE advanced systems. The goal of LTE relaying is to enhance both coverage and capacity and achieve higher spectral efficiency. Relaying is a potential solution to improve the coverage and capacity in LTE-Networks especially at the cell edges which suffer from inter-cell interference. Moreover, using of relay is very attractive because of its potential low cost and simple deployment. This paper shows that deploying of relays can significantly improve both system capacity and coverage. In term of signal to interference noise ratio (SINR), spectral efficiency and transmission path loss the proposed scheme achieves excellent improvement over the conventional scheme without using relay. The fixed relay half-duplex decode – and – forward (DF) has been used as it is the most promising type.

Keywords: Relaying, LTE, SINR, DF, spectral efficiency, throughput and path loss.

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I. *Introduction*

Future wireless communication in Long-Term Evolution Advance (LTE-A) network would have to support very high data rates. As this vision is not feasible with the conventional cellular architecture, in order to increase the capacity, different transmit diversity schemes have been investigated heavily in the past years. Relaying has been proposed as a cost effective method to increase both transmission rate and radio coverage area. The core idea of relaying is to maintain wireless nodes by receiving and retransmitting the signals in addition to the direct communication between a source node and a destination node [1].

There are several classifications of relay nodes (RNs). RNs can be classified into amplify-and-forward (AF) or decode-and-forward (DF) relays. The AF RN simply amplifies the received signal then forwards it. AF RNs cause negligible delays. However, AF RNs also amplify the noise, which can degrade the performance. DF RNs can perform some decoding protocols, so the noise is not propagated through data forwarding. The delay in DF RNs is large compared to AF RNs. Relay nodes can also be classified according to their mode of operation. In the full-duplex mode, the RN transmits and receives data simultaneously at the same time. On the other hand, in the half-duplex mode, the RN does not transmit when it is supposed to receive data. The later type reduces the interference problem when the backhaul link and access link; i.e., the link between the RN and the user equipment (UE), share the same carrier frequencies. In this paper, the half-duplex DF RNs has been used as it is the most promising type [2].

Previous works in the literature that discuss the impact of deploying RNs on the cellular network performance do not consider the importance of the geometric deployment of RNs. In some work, it assumed that the RNs are deployed at a certain radius around the eNB with equal angle spacing [3], [4], [5]. Other work used the RN positions that were optimized for the IEEE 802.16m system [6].

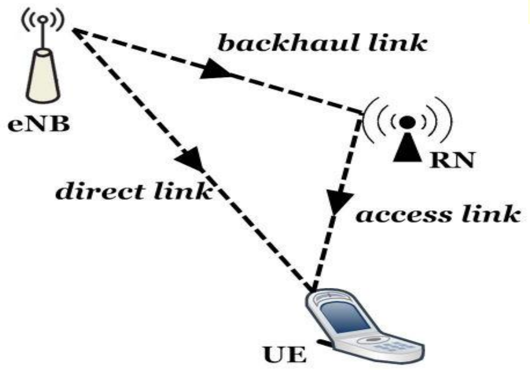

Figure 1: layout two-hop links.

This work proposed a RN deployment in fixed distance , for the case of one relay per sector, and show the impact of the geometric layout of the RNs on the system both capacity and coverage and higher spectral efficiency. The evaluation methodology takes into account the effect of the different downlink frame structures on the system performance. It also takes into account the effect of the path loss of the both RN and eNB in the cell edge.

II. System Description

In this work, any UE can be served either by the eNB directly or by the RN via a two-hop link as shown in Figure 1. The ordinary hexagonal cellular layout with NeNB sites has been considered, each with three sectors and each sector has two RNs as depicted in Figure 2. The frequency reuse factor is assumed to be 3; i.e., all sectors use the same frequency band.

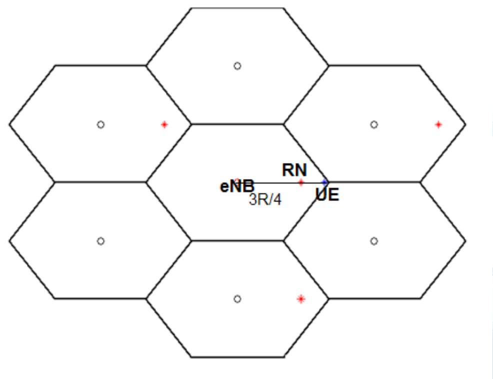

Figure 2: Hexagonal cellular LTE-Network.

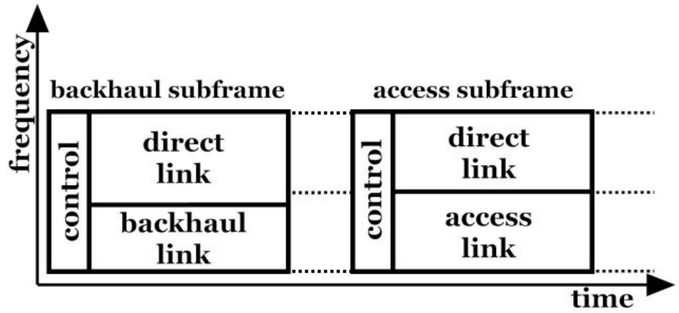

Figure 3: RN Downlink Frame Structure.

With the LTE conventional frame structure, both eNBs and RNs will transmit simultaneously and thus interfere with each other. A relay node downlink frame structure is shown in Figure 3, where the RN first receives the packets from the eNB in the backhaul subframe, and after decoding it, the RN re-encodes and retransmits the packets to the UE in the access subframe.

This pair of downlink subframes is repeated periodically [1]. Different resource blocks are assigned for UEs with direct links and UEs with two-hop links.

III. Mathematical modeling

A mathematical modeling of the SINR and the capacity analysis of the cellular system in the presence of relays for the considered system has been given in this section.

First, when calculating the total interference $I_{tot}$for the conventional LTE frame structure ($\emptyset = 1$), assuming multiuser scheduling is done such that relays in the same sector do not interfere with their eNB sector. When adopting the RN downlink frame structure ($\emptyset = 0$), RNs and eNBs do not interfere with each other. It is assumed that the RNs of the same sector do not interfere with each other due to scheduling.

$$\emptyset = \begin{cases} 0 & \text{RN Downlink frame structure is used .} \\ 1 & \text{LTE conventional frame structure is used.} \end{cases}$$

The SINR of the direct link (Fig.1) to UE u at coordinates (x, y) in sector s of eNB b is calculated as

$$SINR_u^{b,s}(x,y) = \frac{p_s^S \; h_u^{b,s}(x,y)}{I_{tot} + \sigma^2} \tag{1}$$

$$I_{tot} = \sum_{i=1}^{N_{eNB}} \sum_{j=1}^{N_s} P_j^S \, h_u^{i,j}(x,y) - P_s^S h_u^{b,s}(x,y) + \emptyset\left(\sum_{i=1}^{N_{eNB}} \sum_{j=1}^{N_s} \sum_{k=1}^{N_r} P_K^R \, h_u^{i,j,k}(x,y) - \sum_{k=1}^{N_r} P_K^R h_u^{b,s,k}(x,y) \right) \tag{2}$$

where is the equation (1), P_j^S is the power transmitted per sector, $h_u^{i,j}$ total path loss between eNB and UE, P_K^R power transmitted per relay, $h_u^{i,j,k}$ the kth RN in the jth sector of the ith eNB and from the sth sector of the ith eNB. The thermal noise level at the receiver is σ^2.

With few modifications to (2) and denoting the total path loss from the sth sector of the bth eNB to RN r, the rth RN at coordinates (x,y) in the same sector, $h_r^{b,s}$ by (x, y), the SINR of the backhaul link to RN r is given by

where is $h_r^{b,s}$ total loss between eNB to RN? Total Interference equation (3) between other eNBs to own Relay Node.

$$I_{tot} = \sum_{i=1}^{N_{eNB}} \sum_{j=1}^{N_s} P_j^S h_r^{i,j}(x,y) - P_s^S h_r^{b,s}(x,y) + \emptyset \left(\sum_{i=1}^{N_{eNB}} \sum_{j=1}^{N_s} \sum_{k=1}^{N_r} P_K^R h_r^{i,j,k}(x,y) - \sum_{k=1}^{N_r} P_K^R h_r^{b,s,k}(x,y) \right)$$

where $h_r^{i,j}$ is the total path loss between numbers of eNBs to RN. P_K^R is the power transmitter in another relay node. Similarly, the SINR of the access link to UE u at coordinates (x, y) in sector s of eNB b and served by RN r is

where p_r^s is the power transmitted from the rth RN, $h_r^{b,s,r}$ is the total pathloss between RN to UE. Total interference between other relay node and UE is

$$I_{tot} = \sum_{i=1}^{N_{eNB}} \sum_{j=1}^{N_s} \sum_{k=1}^{N_r} P_K^R h_r^{i,j,k}(x,y) - \sum_{k=1}^{N_r} P_k^R h_u^{b,s,k}(x,y) + \emptyset \left(\sum_{i=1}^{N_{eNB}} \sum_{j=1}^{N_s} P_J^S h_u^{i,j}(x,y) - P_s^S h_u^{b,s}(x,y) \right)$$

where $h_r^{i,j,k}$ is the total path loss between relay node and UE.

Second, the point-to-point spectral efficiency (η) of a single-hop link for a given SINR value is given by Shannon's formula as

where the bandwidth efficiency (B_{eff}) and the SINR efficiency ($SINR_{eff}$) are scaling parameters to make Shannon's formula fit with the adaptive modulation and coding curves considered in the LTE standard. It is found that when 64-QAM is set to be the highest modulation scheme, setting B_{eff} and $SINR_{eff}$ to 0.88 and 1.25 respectively, (5) gives an excellent match to practical measurements [7]. For an N-hop link, let η_n be the point-to-point spectral efficiency of the nth hop calculated by (5), then the effective end-to-end spectral efficiency η_{eff} can be calculated by [8] where n is the number of hop between transmitter and receiver.

Third, the effective spectral efficiency as the route selection metric has been used. This metric is chosen to consider the extra resources used by the RN in the multihop connection. For a UE u at coordinates (x,y) and a RN r. η_b^s (r), η_a^s (u) and η_d^s (u) are the spectral efficiencies of the backhaul link from sector s to RN r, access link from RN r to UE u and direct link from sector s to UE u respectively. η_d^s (u), η_b^s(r) and η_a^r(u) are calculated by substituting (1), (3) and (4), in (5). Using (6), the two-hop link effective spectral efficiency (η_{2h}) for UE u through RN r is given by

The best route for UE u at coordinates (x, y), denoted by R(x, y), can be determined as

$$R(x,y) = \arg\max_{s,r}\{\eta_d^s(u), \eta_{2h}^{s,r}(u)\}$$

In equation (7), $\eta_{2h}^{s,r}$ is the two hops spectral efficiency, η_a^r is the access link spectral efficiency and backhaul link η_b^s. And the best route can be determined by

$$R(x,y) = \arg\max_{s,r}\{\eta_d^s(u), \eta_a^r(u)\}$$

where η_d^s is the direct link spectral efficiency.

System level simulation of the LTE-Advanced system has been performed, following, with necessary modifications to include relay nodes. The LTE-Advanced simulation parameters used are summarized in Table I.

IV. System design

MATLAB software has been used to simulate the relay deployment in LTE cellular network. The cell outage is defined as the percentage of locations in the cell with received SINR less than a pre-specified threshold. User Equipment (UE) in such a location can experience call drops or acquisition failure. Cell outage is used as the performance metric for coverage extension.

System level simulation of the LTE-Advanced system, has been performed following [9] with necessary modifications to include relay nodes. The LTE-Advanced simulation parameters used are summarized in Table I. The pathloss from the eNB to a location at distance R from the eNB is dependent whether it is at line of sight (LOS) or non-LOS (NLOS). The likelihood of a location being at LOS or NLOS is determined by the LOS probability function, P_{rob} (LOS) [1]. Assumes that both UEs and RNs always experience LOS/NLOS propagation conditions to their donor eNB and, thus, the so called scenario 3 model of the form is applied.

$$P_L = P_{rob}(LOS) * P_L(LOS) + P_{rob}(NLOS) * P_L(NLOS)$$

Table I: Simulation parameters.

System Parameters	**Value**
Carrier Frequency	2 GHz
Bandwidth	10 MHz
Bandwidth Efficiency	0.88
SINR Efficiency	1.25
Thermal Noise	-174 dBm/Hz
ISD	1Km
Direct Link	P_L(LOS):103.4 + 24.2 $\log_{10}$(R) P_L(NLOS):131.1 + 42.8 $\log_{10}$(R) $P_{rob}(los): min\left(\frac{0.018}{R}, 1\right)\left(1 - e^{-R/0.063} + e^{-R/0.063}\right)$
Backhaul Link	P_L(LOS): 100.7 + 23.5 log10(R) P_L(NLOS): 125.2 + 36.3 log10(R) $P_{rob}(los) = min\left(\frac{0.018}{R}, 1\right)\left(1 - e^{-R/0.072} + e^{-R/0.072}\right)$
Access Link	P_L(LOS): 103.8 + 20.9 $\log_{10}$(R) P_L(NLOS): 145.4 + 37.5 $\log_{10}$(R) $P_{rob}(los) = 0.5 - min\left(5e^{-0.156/R}, 0.5\right) + min\left(5e^{-R/0.03}, 0.5\right)$
Number of eNBs	7
Sector per eNB	3

Tx Power	46dBm
Sector Antenna Gain	15 dB
RN per Sector	One RN
Tx Power	30 dBm
Antenna Gain	5 dB
Antenna Pattern	Omni-directional
Minimum Coupling Loss	45 dB
Rx Noise Figure (NF)	5 dB
Antenna Gain	0 dB
Rx Noise Figure (NF)	9 dB

V. *Results and discussions*

The results in this section show the effect of deploying only one relay per sector in SINR, spectral efficiency and transmission path loss.

A. *Transmission path loss results*

Through extensive system level simulations of the LTEA advanced system the results obtained in the simulations are shown in this section. Figure (4) shows the results of transmission path loss as a function of RNs location from the cell edge. The first curve (solid blue line) represents the transmission path loss of the conventional system (without using RN) while the other curve (dashed green line) represents the transmission path loss of the proposed system (using RN).

This result shows that the path loss is decreased when deployed the RN near to cell edge. Figure (4) shows that using RN achieves approximately 7 dB improvements in transmission path loss over the conventional system when RN located at 0.5 Km from the cell edge.

A. *Signal to interference noise ratio results*

Figure (5) shows the results of SINR as a function of RN location from the cell edge. The solid blue curve represents the SINR of the traditional system (without using RN) while the other dashed green curve represents the SINR of the proposed system (using RN). This result shows that the SINR performance of the considered system after using RNs is outperforms the SINR performance the traditional system. It can be observed that using RN achieves approximately 11 dB improvements in SINR over the conventional system when RN located at 0.5 Km from the cell edge.

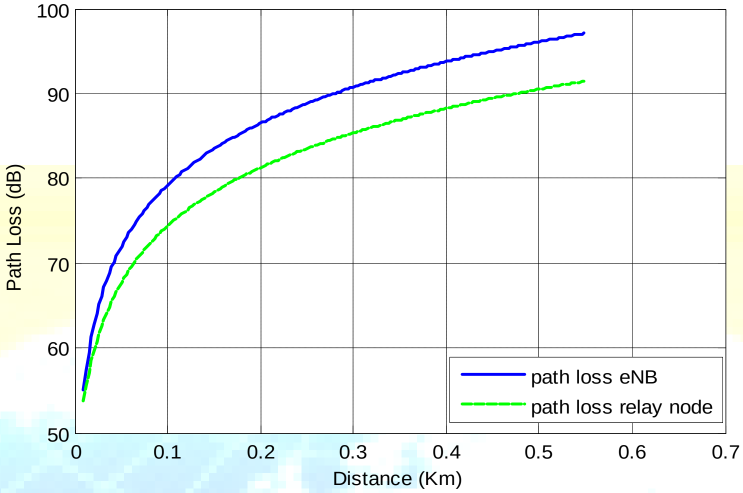

Figure 4: Transmission path loss before and after using RNs.

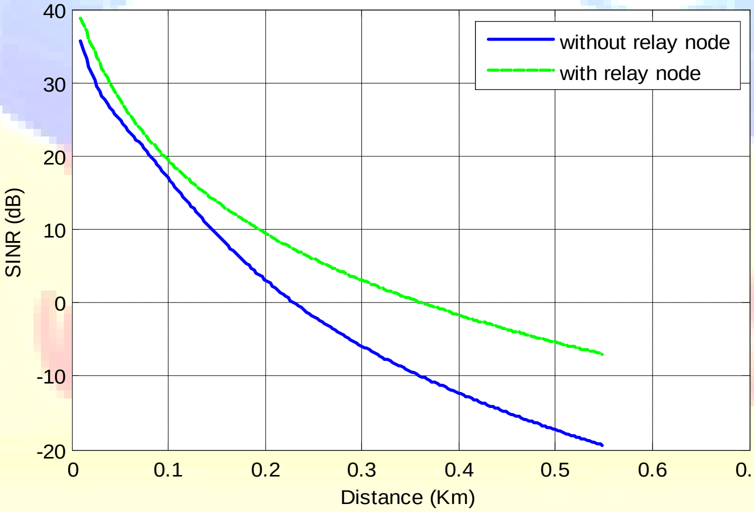

Figure 5: Effect of the distance in SINR with and without using relay.

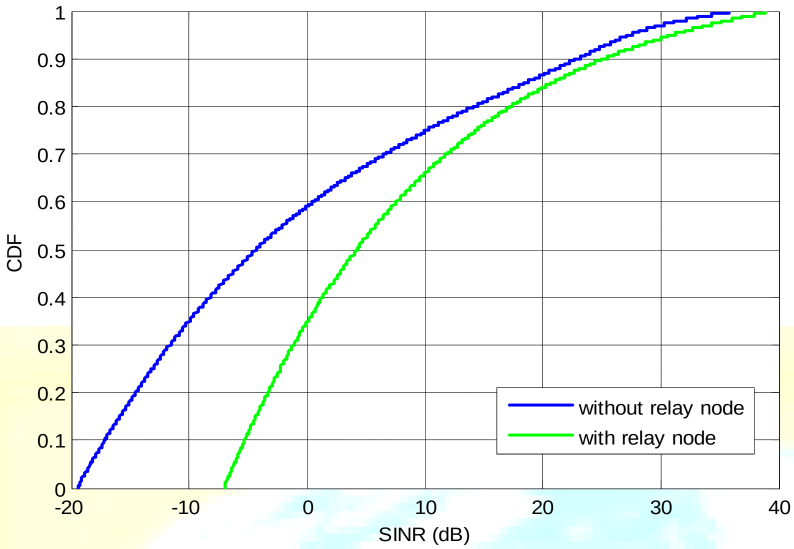

Figure 6: CDF of SINR with and without using relay.

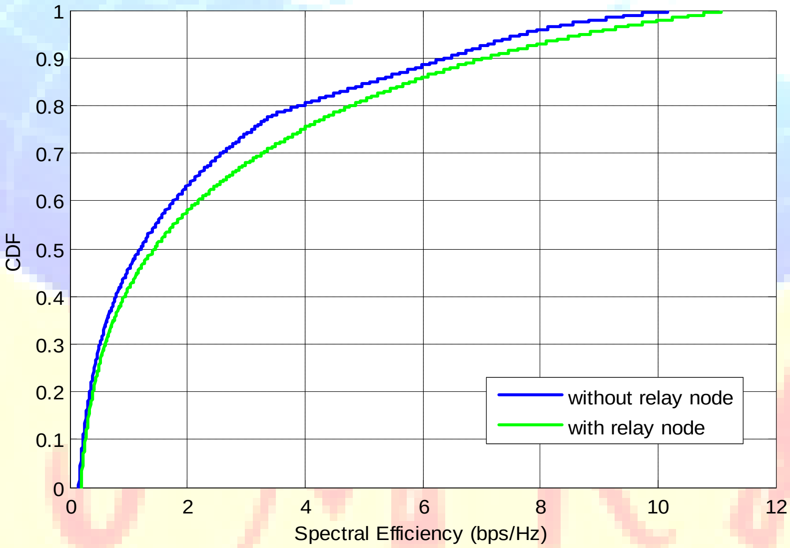

Figure 7: CDF of spectral efficiency with and without using relay.

Figure (6) shows the results of the cumulative distribution function (CDF) versus SINR. The solid blue curve represents the CDF of the considered system without using RN while the other dashed green curve represents the CDF of the considered system using RN. Figure (6) shows that relay deployment results in an enhancement in the CDF of SINR level, especially for the low SINR values.

B. *Spectral efficiency results*

Figure (7) shows the CDF of the effective spectral efficiency for the considered systems with and without using RN. The first solid blue curve represents the spectral efficiency of the scenario without relay while the other dashed green curve represents the spectral efficiency for the scenario with relay. The results in figure (7) show that the CDF of the effective spectral efficiency using RN is outperform the CDF of the effective spectral efficiency without RN deployment.

VI. *Conclusion*

In this work, different scenarios for deploying relay nodes in LTE-Advanced cellular networks have been studied. The results shows that deploying only one relays per sector can extensively increase the system spectral efficiency, increase the SINR in the cell edge, improve the system capacity and reduce the transmission path loss. This paper shows that adopting a RN system capacity and coverage through reducing interference between RNs and eNBs.

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