Proceedings of ICCTA2011

A NOVEL ROUTE SELECTION STRATEGY IN DECODE-AND- FORWARD RELAY ENHANCED LTE-A NETWORK

Chen Sun[1], Xiaojun Wang[1], Weidong Wang[2], Gaofeng Cui[2], Xiaofei Wang[1]

1 School of Electronic Engineering, Dublin City University, Dublin, Ireland
2 School of Electronic Engineering,
Beijing University of Posts and Telecommunications, Beijing 100876, China
chen.sun2@mail.dcu.ie

Abstract

Decode-and-forward (DF) relay has been proposed as a promising technique in LTE (Long Term Evolution)-Advanced to expand cell coverage and improve system performance. Due to the large discrepancy between uplink and downlink capabilities of donor eNodeB (eNB) and Relay Node (RN), the conventional strategies which are based on downlink optimisation lead to some users connecting to the nodes which provide better downlink performance but poorer uplink performance. In this paper, a new route selection strategy is proposed, which considers uplink and downlink jointly. The proposed route selection strategy is compared with a conventional strategy based on downlink spectrum efficiency. Simulation results demonstrate the advantages of the proposed strategy in enhancing system uplink throughput and increasing user's uplink spectral efficiency with no or little degradation of downlink performance.

Keywords: DF relay; LTE-A; route selection; bidirectional optimisation

1 Introduction

Decode-and-forward (DF) relay was brought forward in a 3GPP conference as one of the LTE-A promising candidate techniques [2], with the aim of expanding cell coverage and improving system performance, particularly cell-edge performance. In this paper, Type I DF relay is discussed, which is regarded by UEs as an independent cell [3].

Route selection strategy is an essential radio resource management technique in relay enhanced cellular networks, which has a great impact on system performance. In [6], several existing route selection strategies based on received signal power, signal to interference plus noise ratio (SINR) and spectral efficiency are investigated. These route selection strategies as well as the strategies referred to in [4], [7] and [8] are all based on downlink optimisation.

As described in [5], there is a large degree of imbalance between the transmit power of eNB and RN, which leads to a shaded area between eNB and RN. As shown in Figure 1, a UE is located in the shaded area, which receives larger signal power from the eNB and has less path loss from the RN. Applying the conventional strategies based on downlink optimisation, the UE is more likely to connect to the eNB to achieve better downlink performance, when its uplink performance becomes worse and severe uplink interference to the RN may be generated if the same resources are used in the RN. However, there are a growing number of services with large uplink requirements, such as video calls, FTP upload, and etc. Uplink performance is very critical for the quality of the uplink-preferred services, which will be degraded significantly using these strategies. An alternative strategy to solve this problem is based on path loss which is proposed in [1]. Using this strategy, eNB power needs to be reduced or blank on the resources used by UEs connected to RN and the downlink maximum throughput will decrease due to less downlink resources in eNB. That is to say, existing strategies can either optimize downlink or uplink performance but cannot optimize both at the same time.

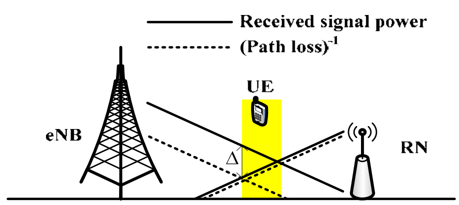

Figure 1 Imbalance between received power and path loss in LTE-A

In this paper, a new route selection strategy is proposed, which jointly considers uplink and downlink requirements of services. The bidirectional requirements are used to decide whether the uplink spectral efficiency or the downlink spectral efficiency would play more important role on route selection. Using such a strategy, uplink performance will be improved without significant degradation of downlink performance.

The rest of this paper is organized as follows. Firstly, system models are introduced in Section 2, and then a route selection strategy based on bidirectional requirements and spectral efficiencies is proposed in Section 3. Simulation results are analyzed in Section 4. Finally, Section 5 concludes the paper.

2 System model

2.1 Network structure

Since Type I RN is an effective method to expand cell coverage and improve system performance, especially in the cell edge, the layout of LTE-A system with relay nodes should be considered carefully.

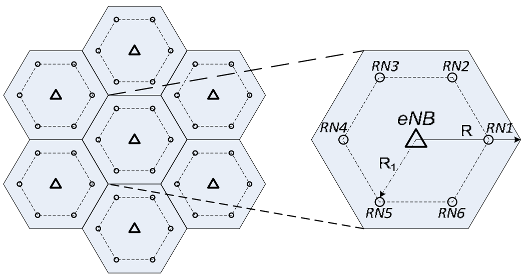

Figure 2 Layout of eNB and relay nodes

As illustrated in Figure 2, a seven-cell network and the layout of a six-relay deployed LTE-A cell are considered in this paper; the eNB is located at the cell centre, which is marked as a triangle; whilst six RNs are each located between the eNB and one of six vertices, which are denoted as circles. R is the cell radius and R_1 stands for the distance between eNB and RN, which is 2/3 of R.

2.2 Frame configuration

In order to provide better support for asymmetric traffic, the frame structure based on TDD technique is considered in this paper, which is inherited from the frame structure type 2 in [10]. As shown in Figure 3, subframe #2 and #7, which are immediately following special subframes, are reserved for uplink channel, whilst subframe #0, #3, #4, #5, #8, and #9 are reserved for downlink channel to support larger downlink throughput. There are two arrows in every subframe, which indicate 2 types of transmission links. The longer arrows represent the direct links which are between eNB and UE, while the shorter arrows represent the relay links which are between eNB and RN, or the access links which are between RN and UE. Note that there are 2 special frames for DwPTS, GP and UpPTS.

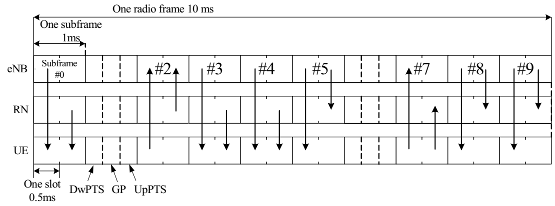

Figure 3 Frame configuration for DF relay

Since the quality of the relay links is very critical to the system performance, the relay links are isolated from the access links and the direct links to avoid possible severe interference. Thus, as the subframe configuration is displayed in Figure 3, the direct links and the access links can reuse the whole radio resources in subframe #0, #3, #4 and #7 to achieve as large throughput as possible, while the relay links and the direct links are using the orthogonal physical radio blocks in subframe #2, #5, #8 and #9 to reduce the interference in relay links. Note that the relay links will use one timeslot in these subframes while the direct links are using the other one in this paper.

2.3 Service type

The full-buffer traffic model is usually used to investigate the maximum system throughput rather than uplink and downlink performance of individual services. Moreover, all services are considered as the same type, which is not suitable for this paper. Three types of services are defined in this paper with different uplink requirements α and downlink requirements β. The three types are uplink-preferred services, downlink-preferred services, and symmetric services. α and β stand for the amount of the resources which the services need to occupy. If there are not enough resources assigned to a service, the service will occupy as many resources as possible.

3 A novel route selection strategy

3.1 Spectral efficiency

Spectral efficiency is taken as the route selection metric in this paper. The actual spectral efficiency will only be calculated by mapping the SINR to the modulation and coding scheme (MCS). Nonetheless, Shannon's formula can be used to estimate the spectral efficiency, which simplifies the analysis of the spectral efficiency. The SINR and spectral efficiency in a Physical Radio Block (PRB) r between a transmitter node i and a receiver node j is expressed as

$$SINR_{ijr} = \frac{PL_{ij} \bullet P_i}{\sum_{k \in K} PL_{kj} \bullet P_k + N_j} \quad (1)$$

$$SE_{ijr} = \log_2(1 + SINR_{ijr}) \quad (2)$$

where K is a set of nodes which are using PRB r, PL_{ij} is the pathloss between node i and node j, and P_i is the transmitting power of node i. N_j is white Gaussian noise of node j.

3.2 Bidirectional Optimisation Route Selection Strategy

When a user starts its transmission, it will choose a route, either the direct route or the two-hop route via a RN in order to obtain better performance. As for different types of services with different uplink and downlink requirements, the route selection strategy is not expected to be only based on downlink or uplink optimisation. In order to improve uplink performance without significantly degrading downlink performance, we consider uplink and downlink requirements of services as weights of uplink and downlink spectral efficiencies so as to form the new total spectral efficiencies and optimise the total performance of different types of services. As both uplink and downlink performance is optimised according to the types of the services, the proposed strategy is named Bidirectional Optimisation (BO) strategy in this paper. The spectral efficiencies for the direct transmission and the two-hop transmission can be expressed as

$$SE_{direct} = \frac{1}{\alpha + \beta}(\alpha \bullet \overline{SE^{available}_{direct-UL}} + \beta \bullet \overline{SE^{available}_{direct-DL}}) \quad (3)$$

$$SE_{2hop} = \frac{1}{\alpha + \beta}(\alpha \bullet \overline{SE^{available}_{2hop-UL}} + \beta \bullet \overline{SE^{available}_{2hop-DL}}) \quad (4)$$

The route selection steps are as follows.

1) There are one eNB and one RN selected as the candidate access stations according to the least pathloss,
2) SINR of direct links, access links and relay links are obtained to calculate spectral efficiencies.
3) The access decision of the BO strategy is determined as follow:

$$r_s = \arg\max(SE_{direct}, SE_{2hop}) \quad (5)$$

4 Simulation results

In this paper, a Matlab-based static system-level simulator is designed to investigate the performance of the proposed strategy and compare it with that of a conventional strategy based on downlink optimisation.

4.1 Simulation assumptions

Table 1 Simulation parameters

Parameters	Values
Carrier frequency	2GHz
Frequency bandwidth	20MHz
PRB number	100 per 0.5ms timeslot
Inter-site distance	500m
Number of Relays	6 per cell
Distance-dependent path loss (R in km in all formulas)	Random LOS/NLOS based model is used.
	eNB to UE: PL_{LOS}(R)= 103.4+24.2log10(R) PL_{NLOS}(R)= 131.1+42.8log10(R) LOS probability: Prob(R)=min(0.018/R,1)*(1-exp(-R/0.063)) +exp(-R/0.063)
	Relay to UE: PL_{LOS}(R)=103.8+20.9log10(R) PL_{NLOS}(R)=145.4+37.5log10(R) LOS probability: Prob(R)=0.5-min(0.5,5exp(-0.156/R)) +min(0.5, 5exp(-R/0.03))
	eNB to Relay: PL_{LOS}(R)=100.7+23.5log10(R) PL_{NLOS}(R)= 125.2+36.3log10(R) LOS probability: Prob(R)=min(0.018/R,1)*(1-exp(-R/0.072)) +exp(-R/0.072)
Shadowing std	Lognormal shadowing is used
	Direct link: 0 dB for LOS; 8 dB for NLOS
	Backhaul link: 0 dB for LOS; 6 dB for NLOS
	Access link: 0 dB for LOS; 10 dB for NLOS
Channel model	Typical Urban (TU) used for all links
eNB power	40 watts; 46 dBm
Relay power	1 watt; 30 dBm
Thermal noise density	-174 dBm/Hz
Power control	P0=-56dBm, alpha=0.6
Minimum distance	between eNB and relay node: 70m
	between UE and eNB: 35m
	between UE and relay node: 10m
	among relay nodes: 40m

A seven-cell network is generated with wraparound in which six relay nodes are deployed per cell. Relay nodes' locations are planned and fixed according to the network structure described in Section II. Round-robin scheduler is applied to the access link and the direct link in this simulation. Resources in the backhaul link are allocated to the relay nodes according to the throughput requirements of the relay nodes. Note that uplink-preferred service occupies 20 PRBs in the uplink and 2 PRBs in the downlink, symmetric service asks for 2 PRBs both in the uplink and downlink, while downlink-preferred service takes 2 PRBs in the uplink and 20 PRBs in the downlink. Assuming that, 1/9, 1/3, 5/9 of total services are considered as uplink-preferred services, symmetric services and downlink-preferred services respectively. Most of the important simulation assumptions are described in Table 1. More simulation assumptions can be found in [2].

4.2 Simulation results and analyses

In order to investigate the Bidirectional Optimisation (BO) route selection strategy and the conventional Downlink Optimisation (DO) route selection strategy which is also based on downlink spectral efficiency, we compare the system performance and the users' spectral efficiencies in the uplink and downlink using these two strategies. The numbers of users placed in every cell are identical and increase from 10 to 120 so as to simulate the scenarios from the light-loaded system to the heavy-loaded system. For each user number case, 500 snapshots are run to collect the simulation results.

Figure 4 and Figure 5 show the uplink throughput and the downlink throughput in a cell using different route selection strategies with different user numbers per cell.

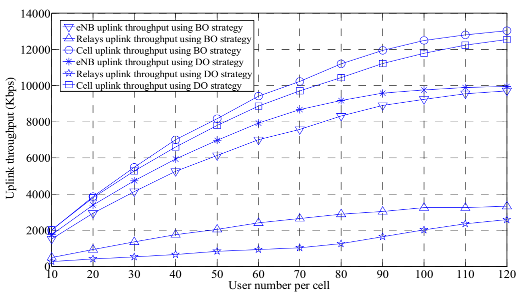

Figure 4 Uplink throughput of donor eNB, relay nodes and the total cell

As illustrated in Figure 4, the cell uplink throughput using the BO strategy is larger than that using the DO strategy when the user number is more than 30 per cell. Besides, the cell uplink throughput consists of two parts, the uplink throughput of eNB and the total uplink throughput of six relay nodes. It can be observed that relay nodes provide more proportion of uplink throughput using the BO strategy than that using the DO strategy, and as for eNB, the situation is otherwise. In addition, it is worthy to point out that when the user number per cell exceeds 100, the uplink throughput of eNB using the DO strategy and the total uplink throughput of relay nodes using the BO strategy don't increase significantly because these nodes are heavy-loaded. Meanwhile, the gap between the total cell uplink throughput using the BO strategy and the DO strategy is reducing.

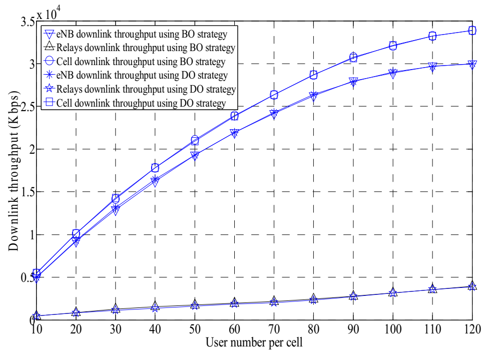

Figure 5 Downlink throughput of donor eNB, relay nodes and the total cell

It can be seen in Figure 5 that the downlink throughputs for BO strategy and DO strategy are almost the same. It shows that applying BO strategy will not influence the downlink performance significantly compared with the DO strategy because bidirectional requirements are considered by the BO strategy.

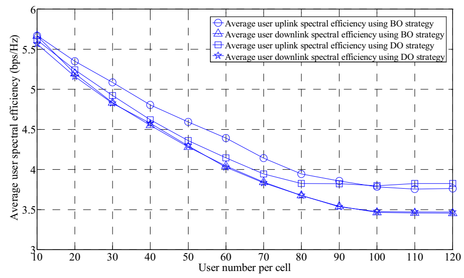

Figure 6 Average downlink and uplink spectral efficiencies

Figure 6 presents average uplink and downlink spectral efficiencies using the BO strategy and the DO strategy separately. Along with the growth of the user number per cell, the spectral efficiencies in all cases decreases gradually due to growing user number and increasing interference. However, the degradation of uplink spectral efficiencies is insignificant when the user number is more than 90, because there is little extra resource for the incremental portion of users and thus little increase in interference.

Generally speaking, the BO strategy shows its advantage over the DO strategy in getting higher uplink spectral efficiencies. Nonetheless, there is an exception that the uplink spectral efficiency using the BO strategy is lower than that using the DO strategy when the user number per cell is more than 100. This is because more PRBs are occupied and more interference is generated by the BO strategy due to larger proportion of the user throughput is transmitted by relay nodes. It can also explain why there is less uplink throughput gain when the user number per cell is more than 100 as it is pictured in Figure 5. Meanwhile, the BO strategy keeps roughly the same downlink spectral efficiency as the DO strategy.

5 Conclusions

Simulation results indicate that the Bidirectional Optimisation strategy is better than the Downlink Optimisation strategy in getting larger uplink throughput and higher uplink spectral efficiency with little decline in the downlink throughput and the downlink spectral efficiency. Besides, the uplink spectral efficiency using the BO strategy is higher than that of the DO strategy when the user number per cell is under 90, and is lower when the user number per cell is above 100. As a result, it can be concluded that the proposed BO strategy is more effective when the system is not heavily loaded.

References

[1] 3GPP R1-083813, "Range expansion for efficient support of heterogeneous networks", Qualcomm Europe , Oct, 2008.

[2] 3GPP TR 36.814 v0.4.1, "Further Advancements for E-UTRA; Physical Layer Aspects", Feb. 2009.

[3] 3GPP R1-091112, "Text proposal on type 1 relaying", RAN1-56, Feb. 2009.

[4] Letian Rong, Elayoubi S.aE., Haddada O.B., "Impact of Relays on LTE-Advanced Performance", 2010 IEEE International Conference on Communications (ICC), 23-27 May 2010

[5] 3GPP R1-083809, "New Interference Scenarios in LTE-Advanced", Qualcomm Europe, Oct, 2008

[6] Zhangchao Ma, Kan Zheng, Wenbo Wang, Yang Liu, "Route Selection Strategies in Cellular Networks with Two-Hop Relaying", 5th International Conference on Wireless Communications, Networking and Mobile Computing, 2009. WiCom '09, 24-26 Sept. 2009

[7] Mugen Peng, Na Yang, Wenbo Wang, Hsiao-Hwa Chen, "On Interference Coordination for Directional Decode-And-Forward Relay in TD-LTE Systems", 2010 IEEE International Conference on Communications (ICC), 23-27 May 2010

[8] Won-Hyoung Park, Saewoong Bahk, Resource management policies for fixed relays in cellular networks, Computer Communications, Volume 32, Issue 4, 4 March 2009, Pages 703-711,

[9] Eunhyun Kwon, Jaiyong Lee, Mi-Sun Do, Kyunghun Jung , "Comparison of symmetric and asymmetric routing for fixed two-hop cellular relaying network", IEEE Communications Letters, vol.11, no.5, pp.378-380, May 2007

[10] 3GPP TR 36.211 v8.8.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation", Sep. 2009.