Specific buffer-aided full duplex relaying over LTE advanced networks

Ramachandran Vijayarani* and
Lakshmanan Nithyanandan

Department of Electronics and Communication Engineering,
Pondicherry Engineering College,
Puducherry – 605 014, India
Email: vijee_er@pec.edu
Email: nithi@pec.edu
*Corresponding author

Abstract: Full duplex relaying is an emerging technique to transmit and receive simultaneously at the same frequency for enhancing the attainable spectral efficiency in long term evolution advanced (LTE-A) network. The adoption of buffering over relay network outperforms and achieves better outage probability than the conventional relaying. In case of full duplex relaying (FDR) both transmission and reception are happening in same orthogonal channels, the increase in buffer length and higher delay deteriorates the system quality of service (QoS). To achieve both spectral efficiency and QoS, full duplex relay with the separate buffers for receiving and re-transmitting is proposed. The optimal trusted relay selection scheme is incorporated for maximising the security with effective signal-to-interference and noise ratio, which significantly improves the relaying transmission and further Tabu search-based metaheuristic algorithm is used for dealing with the trusted relay selection problem. The performance of three models, i.e., FDR without buffer-aided (conventional FDR), FDR with general buffer and FDR with specific buffer is investigated and compared in terms of outage probability and throughput. The simulation results revealed that the proposed FDR with specific buffer-aided scheme provides better performance compared with other FDR methods.

Keywords: buffer-aided; full duplex relaying; FDR; LTE advanced; quality of service; QoS; tabu search.

Reference to this paper should be made as follows: Vijayarani, R. and Nithyanandan, L. (2017) ‘Specific buffer-aided full duplex relaying over LTE advanced networks’, *Int. J. Mobile Network Design and Innovation*, Vol. 7, No. 1, pp.15–21.

Biographical notes: Ramachandran Vijayarani received her Bachelor of Engineering degree in Electronics and Communication Engineering and Master of Engineering degree in Applied Electronics from Anna University, Tamilnadu, India in 2008 and 2010 respectively. She has two years of teaching experience and is currently pursuing her PhD in the Department of Electronics and Communication Engineering from Pondicherry Engineering College, Puducherry, India. Her research interests include cooperative communication, MIMO, and relay networks.

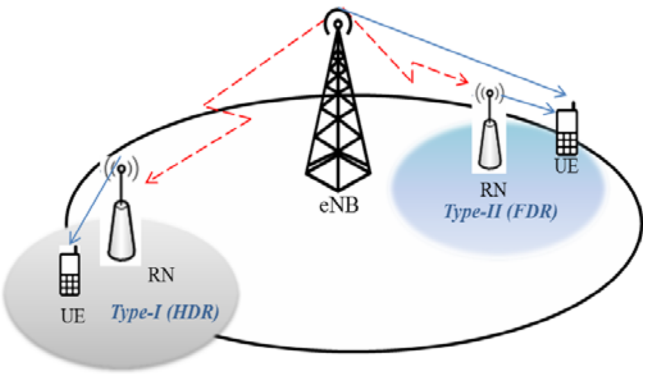
Lakshmanan Nithyanandan received his Bachelor of Engineering from University of Madras in 1992, Master of Technology in 1999 and PhD in 2006 from Pondicherry University. He is currently working as a Professor in Department of Electronics and Communication Engineering, Pondicherry Engineering College, Puducherry, India. He is a Gold Medalist in Post Graduate and has been awarded with Chief Minister Medal of Pondicherry for his outstanding performance. He has more than 50 publications in national/international conferences and journals. His areas of interest include sensor networks, telemedicine, spread spectrum techniques, and wireless communication.

1 Introduction

The third-generation partnership project (3GPP) long term evolution advanced (LTE-A) (4G) networks comprise of different transmission techniques such as; enhanced inter-cell interference coordination (eICIC), coordinated multi-point (CoMP) transmission/reception, enhanced MIMO, and relaying to provide high data rates (1 Gbps and 500 Mbps downlink and uplink respectively) and spectral efficiency (Akyildiz et al., 2010).

Relaying is considered as a promising tool to enhance the throughput, coverage extension and network capacity in LTE-A networks (ITU, 2008; Yang et al., 2009; Hoymann et al., 2012). Bulakci et al. (2013) explores about relaying, the wireless link between the eNB and the relay node (RN) is referred as a backhaul link and the wireless link between the eNB and user equipment (UE) or between the RN and UE is called an access link. The 3GPP standard defines two types of relaying in LTE-A networks (Ghosh et al., 2010; Loa et al., 2010; Teyeb et al., 2009) as illustrated in Figure 1. A *Type I* relay behaves as an eNB, which has its own physical cell and becomes distinct from the donor macro cell. These RNs are non-transparent relay, thus are unable to transmit to the UEs and receive from the serving eNB simultaneously. A *Type II* relay acts as a repeater, which does not have a cell identity. It is transparently participating in data forwarding to all UEs within its coverage area in both downlink and uplink and the UEs are not aware of its existence (Lin et al., 2014; Li et al., 2013; Zhang et al., 2014), also *Type II* RN can be used as a full-duplex relay (FDR). This paper considers the *Type II* relay due to the purpose of enhancement of throughput and quality of service (QoS) of UE especially for cell edge user or in an indoor wireless environment without independent cell creation as Li et al. (2013).

Figure 1 LTE-A relay networks (see online version for colours)



On the other hand, as the wireless channels have broadcast nature, the wireless networks are threatened by eavesdropping, message modification, and node impersonation. Unauthorised users are attempting to extract information from legitimate users. Recently, significant research has been carried over secrecy at the physical layer to protect the confidentiality, integrity, and authenticity of transmitted data (Mukherjee et al., 2014). The source desires to use the relay to communicate with the destination, but at the same time intends to shield the message from the relay. Chen et al. (2015) investigated a typical model of a relay channel with physical layer secret key generation (PHY-SKG) rate. Therefore, to ensure the security, the selected relay nodes should be trusted one.

In full duplex relaying (FDR) both transmission and reception happens over the same frequency band at the same time, rather than over two orthogonal time slots in half duplex systems, the spectral efficiency of the networks has to be improved with increased data rates (Zhang et al., 2015). Thus, the FD relay that received the signal from one node is subsequently transmitted to the destination node. With the adoption of buffering over RN, the degrees of freedom of selecting different relays for transmission and reception are increased. Buffering is a promising solution for cooperative networks and motivates the various new protocols and transmission schemes, even though it may result in increased delay (Zlatanov et al., 2014). In literature (Zang et al., 2015; Liu et al., 2015; Cui et al., 2014), relays with lack of data buffers was assumed. Liu et al. (2015) discusses about the energy efficiency aspect of resource allocation in FDR systems. Opportunistic full-/half-duplex relaying schemes are studied (Xia et al., 2015) where the effects of imperfect channel state information (CSI) and transmit imperfection are taken into account.

In buffer-aided relaying, the selected relay receives a packet from the source, decodes it, and accumulates the information in its buffer. On the other hand, if the relay is selected to transmit, RN extracts the stored information from its buffer, maps it into a packet, and retransmits the packet to the corresponding destination. Chen et al. (2014) proposes FDR with buffer and compares the throughput performance with FDR without buffer, FDR with unlimited buffer, and FDR with limited buffer respectively. Generally, buffer-aided relaying protocols have increased complexity than conventional protocols. Nevertheless, buffer-aided relaying leads to significant performance gains in cooperative communication networks with time varying link qualities.

Since an FD system has to process twice as many packets as an HD-based system due to its essential capability of concurrently transmitting and receiving in a single time/frequency slot, both the packet loss and the delay may become more severe for FD than for HD unless the buffer's queue length in the former is significantly increased (Yang et al., 2015). Moreover, the use of general buffer for both transmission and reception made difficult for storing and restoring the packets in FDR and causes higher delay, hence a well-designed buffer-aided relaying is needed. In this paper, FD relay with specific buffer is proposed where separate buffer for transmission and reception is used, to achieve a better outage probability and throughput. The use of separate buffer leads to better buffer management as well as reduce the signal outage than general buffer FDR. Moreover, the optimal relay has been selected based on the knowledge of link quality between RN and UE. In this paper, tabu search algorithm has been developed for potential trusted relay selection. It is a trajectory-based metaheuristics algorithm for addressing combinatorial optimisation problems. It was first introduced by Glover and Laguna (1997) and basically performs the neighbourhood search that keeps track of the up-to-now search path to avoid to be trapped into local optima of the solution domain (Costa et al., 2015). The performance of proposed relaying protocol is compared with FDR without buffer and FDR with general buffer respectively.

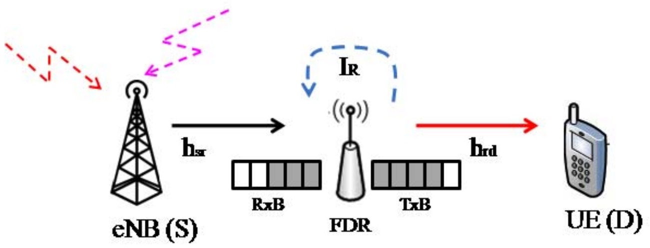
The rest of this paper is organised as follows. Section 2 presents the system model. In Section 3 optimal relay selection and proposed buffering model are presented. Section 4 discusses simulation results. Finally, concluding remarks are given in Section 5.

2 System model

Consider a simple cooperative network consisting of eNB (source *S*), one UE (destination *D)* and a cluster *C* with *K* decode and-forward (DF) relays $R_k \in C(1 \leq k \leq K)$ with buffer. All nodes are characterised by in-band *Type II* relay with FD constraint and therefore they can transmit and receive simultaneously. Assume that there is no direct link between the source and the destination due to the strongest path loss and attenuation in the link, hence communication can be established only via relays.

In-band *Type II* relay characterised by both source and relay node with the same time-frequency resource is assumed and the relay nodes in the FD mode is equipped with two antennas such as one used for receiving and one for transmitting, denoted as *N* and *M*. The proposed system model is shown in Figure 2. Each relay R_k, $k \in K$ holds a separate buffer Q_r^k and Q_t^k for receiving and transmitting antenna respectively. The length of buffer is denoted as L_r^k and L_t^k (number of data elements) where receive buffer (RxB) can store source data that has been decoded at the relay and re-transmit buffer (TxB) can hold the forward data to the destination. The parameter $l_k, l_t \in Z^+$; $0 \leq l_k \leq L_r^k$, $0 \leq l_t \leq L_t^k$ denotes the number of data packets that are stored in the buffer Q_r^k and Q_t^k; at the beginning, each buffer is empty (i.e., $l_k = 0$, $l_t = 0$ for all *k, t*). The total length of both the buffer is denoted as $L(L_r^k = L_t^k = L/2)$.

Figure 2 Specific buffer-aided full duplex relay (Type II) (see online version for colours)



In case of buffer-aided FDR, the relay not only forwards the data transmitted by the source at the current time slot, also draws out the data from the buffer to transmit them to the destination so as to achieve the maximum forward rate and rest of the data can be stored into buffer. Hence, with the usage of separate buffer, the system throughput is improved comparing with the conventional FDR. Assume that the reliable feedback channels are deployed and perfect CSI is estimated accurately.

Thus, at time slot *i,* the relay receives $x[i]$ from the source and transmits the data $t[i]$ simultaneously, using DF protocol. The received signal at the relay R_k is given by

$$y_r[i] = h_{sr}\sqrt{P_s}\,x[i] + I_r\sqrt{P_r}\,x_k[i] + n_r[i] \tag{1}$$

where h_{sr} is the channel link between the source and the relay R_k and I_r is the residual self loop interference between transmit and receive antenna. $x[i]$ is i^{th} signal with unit power transmitted from source and $x_k[i]$ denotes the transmitted data symbol vector from the k^{th} relay. The signal received at the destination is given by

$$y_d[i] = h_{rd}\sqrt{P_r}\,t[i] + n_d[i] \tag{2}$$

where h_{rd} is the channel link between the relay and the destination. The transmitted signal by relay $t[i]$ is given by

$$t[i] = \sqrt{\frac{P_r}{P_s}}\,x[i - t_0] \tag{3}$$

where P_s and P_r respectively denotes the transmit power at the source and the relay, assume that $P_s = P_r = P$ and τ_0 represents the processing delay; $n_r[i]$ and $n_d[i]$ denotes the additive white Gaussian noise(AWGN) with zero mean and variances are represented by σ_r^2 and σ_d^2 respectively. With the assumption of $\sigma_r^2 = \sigma_d^2 = \sigma^2$ at the relay and the destination, the signal-to-interference-plus-noise ratio (SINR) at k^{th} relay R_k from source can be written as

$$\gamma_{sr}^k = \frac{P_s|h_{sr}|^2}{P_s|h_{sr}|^2 + \sigma^2} \tag{4}$$

The SINR at UE from relay R_k is expressed as

$$\gamma_{rd}^k = \frac{P_r|h_{rd}|^2}{P_r\,|h_{rd}|^2 + \sigma^2} \tag{5}$$

The end-to-end SINR via the relay R_k can be obtained as

$$\gamma_{sd}^k = \frac{P_s P_r|h_{sr}h_{rd}|^2}{P_r^2|h_{rd}I_r|^2 + P_r|h_{rd}|^2\sigma^2 + \sigma^2} \tag{6}$$

The self-loop interference I_r can be obtained through sufficient training (Yang et al., 2015). Assume that the source transmits the data elements with the maximum rate of $C_s^k[i] = \log_2(1 + \gamma_{sr}^k)$ according to the quality of the channel link between source and RN. The relay also transmits the data elements with the maximum rate of $C_r^k[i] = \log_2(1 + \gamma_{rd}^k)$ according to the quality of R-D link to the FDR model. However, in buffer-aided FDR the transmit rate of the relay also includes the amount of bits in the buffer. Hence, it is stated as the minimum rate between the amount of bits stored in the buffer and the maximum transmit rate of the R-D link C_r^k and is equal to the received rate of the destination C_d^k.

3 Optimal trusted relay selection strategy and specific buffer-aided FDR model

To achieve the robust performance in relay transmission, it is essential to select a potential relay. In the proposed scheme the optimal relay has been selected by estimating the successful reception probability at receiver from each *K* nodes using heuristic tabu local search algorithm. The relay with maximum probability estimated at UE is selected as a potential relay. For relay selection the CSI between RN and UE alone is considered, hence the additional signalling overhead is reduced. Assume that UE is able to decode correctly the received signal only when the instantaneous SINR between RN and D is not less than a threshold value of γ_o. The successful reception probability $\Pr_{rd}^{k}$ is the probability that a packet successfully received at user end from RN can be written as (Jin et al., 2014)

$$\Pr_{rd}^{k}[i] = \Pr\{\gamma_{rd}^{k} \geq \gamma_o\} = \exp\left(-\frac{\gamma_o}{P_t / N_t}\|r-d\|^{\alpha}\right) \tag{7}$$

where P_t is the transmit power, N_t is the power of additive white Gaussian noise. The path-loss effect is denoted by $g_{rd} = \|r-d\|^{\alpha}$, where α is the path-loss exponent and $r-d$ is the Euclidean distance. Since the location information is available to RN, the distance between the relay and destination can be calculated. Based on the successful reception probability with buffer status, the optimal relay can be selected as

$$R_k^{*}[i] = \arg\max_{k\in\{1,\ldots K\}}\left\{\bigcup_{R_k:L_r<L,L_t>0}\Pr_{rd}^{k}\right\} \tag{8}$$

The relay selection scheme (8) is optimal in minimising the outage probability and error rate. Furthermore, from the practical scenario, while a secure communication is maintained, the received SINR at the destination is increased and therefore, the instantaneous secrecy rate is increased (Kuhestani et al., 2016). The potential RN selected by equation (8) has been a trusted node to ensure the security. Hence, the relay with maximum of the instantaneous secrecy rate is chosen to act as a potential trusted node. Let R_k^{*} denotes the index of the optimal trusted relay and is given as

$$R_k^{*} = \max_{1\leq k\leq K} C_{\text{secr}}^{(\text{k})} \tag{9}$$

where $C_{\text{secr}}^{(k)}$ is the instantaneous secrecy rate corresponding to the selected relay R_k^{*}. The instantaneous secrecy rate evaluated by Mukherjee et al. (2014) is given as

$$C_{\text{secr}}^{(\text{k})} = \frac{1}{2}[\log_2(1+\gamma_{rd}^{k}) - \log_2(1+\gamma_{sr}^{k})]^{+} \tag{10}$$

where $[\text{x}]^{+} = \max\{0, \text{x}\}$. It is to be noted that the goal is to transmit the data securely, that is, no information leakage should occur (Mukherjee et al., 2014). Therefore, the instantaneous secrecy rate of the selected relay R_k^{*} (Kuhestani et al., 2016) is given by

$$C_{\text{secr}}^{(k)} = \frac{1}{2}\left[\log_2(1+\gamma_{rd}^{k}) - \underbrace{\max_{1\leq k\leq K}\log_2(1+\gamma_{sr}^{k})}_{\text{zero information leakage}}\right]^{+} \tag{11}$$

The optimal trusted relay selection has been performed using tabu search (TS) algorithm (El Rhazi and Pierre, 2009). Starting from the initial solution, TS generates a new alternative R' in the neighbourhood of the alternative R with a function that transforms R into R'. The moves are stored in a set N, called as tabu list. The size of N is bounded by a parameter L, known as tabu list size. If $N = L$, before adding a move to N, one must remove an element in it, the oldest one in general. A tabu move can always allowed to be chosen if it creates a solution better than the incumbent solution, up to the best objective value obtained so far. The trusted RN selection using Tabu search algorithm is summarised in Table 1.

Table 1 Trusted relay selection using tabu search algorithm

Step 1	***N*** : Number of RN set	
Step 2	$R = R_k$;	*% initial solution*
Step 3	$R' = R_k^{*} = 0$;	*% optimal RN*
Step 4	***Length*** $(L) = N$;	*% Max. tabu list length*
Step 5	***Set*** $L = \{\ \}$	*% Initialise the tabu list*
Step 6	**for** $n = 1$ to N	
Step 7	**while** there is a neighbour of RN with better quality by equations (7) and (11) **do**	
Step 8	**if** $R_k \notin L$ **then**	
Step 9	**if length (*L*) > *N***	
	Remove the least RN from L;	
	Set $R_k \in L$;	
	update tabu list	
	endif	
	endif	
Step 10	**if** $R_k^{*} > R$ by equations (8) and (9) **then**	
	$R = R_k^{*}$;	*% selected R_k is optimal and trusted*
	Stop the search; Go to Step:13;	
	elseif	
	Reject the RN R_k; Go to Step:7;	
	endif	
Step 11	**end while**	
Step 12	**end for**	
Step 13	**Return** R_k^{*}	

3.1 Proposed buffering model at FDR

In the proposed specific buffer-aided scheme, the usage of separate buffer improves the system performance and introduces a new paradigm for system design. However, it has its own practical challenges. In particular, storing and recovering packets in the specific buffer of the relay reduces the additional delay than FDR with general buffer. Moreover, buffer-aided relaying requires the CSI and may require monitoring of the status of the buffer at each time slot. Let RxB and TxB denotes two finite-size buffers of size B bits each at FD relay in which the received and retransmitted information from eNB and to the user are stored, respectively. $Q_j[i]$, $j \in \{r, t\}$ denotes the amount of normalised information in bits/symbol available in buffer at i^{th} time slot. The relay decodes this information and stores in buffer RxB. The rate of information transmitted from S is given by

$$C_s^k[i] = \log_2(1+\gamma_{sr}^k[i]) \tag{12}$$

Therefore, at receiving antenna the amount of information stored in buffer RxB increases to

$$Q_r^k[i] = Q_r^k[i-1] + C_s^k[i] \tag{13}$$

At time slot i, the signal received at RN $y_r[i]$, that is perhaps physically closer to $x[i]$ than $y[i]$. With channel noise the relayed signal is $x_k[i]$. In DF relaying protocol the relay decodes the source message in one block and transmits the reencoded message in the following block. The achievable rate of DF protocol at RN is given as (Wang et al., 2005)

$$C_R^k[i] = \max_{p(x,x_k)} \min \begin{pmatrix} I(x[i]; y_r[i] / x_k[i]), \\ I(x[i], x_k[i]; y[i]) \end{pmatrix} \tag{14}$$

In specific buffer-aided relay the rate of transmitting bits from RXB to TXB is written as

$$C_r^k[i] = \min\left\{C_s^k[i] - C_R^k[i]\right\} \tag{15}$$

The transmit rate from RN C_d^k denotes the bits received at UE per time slot and is the minimum between the maximum rate C_r^k and the amount of bits stored in the buffer at i^{th} time slot is expressed as

$$C_d^k[i] = \min\left\{\log_2(1+\gamma_{rd}^k[i]), Q_t^k[i-1] + C_r^k[i]\right\} \tag{16}$$

Simultaneously, in transmitting antenna the amount of information is forwarded to UE k, the transmit buffer decreases to

$$Q_t^k[i] = \min\left\{Q_t^k[i-1] + C_r^k[i] - C_d^k[i], B\right\} \tag{17}$$

Hence, the throughput of the proposed FDR network is denoted by

$$\begin{aligned} \tau &= \lim_{N\to\infty} \frac{1}{N} \sum_{i=1}^{N} C_d^k \\ &= E\left[\min\left\{\log_2(1+\gamma_{rd}^k[i]), Q_t^k[i-1] + C_r^k[i]\right\}\right] \end{aligned} \tag{18}$$

The outage probability of the proposed FD relay is defined as

$$P_{out}(R_k^*) = \Pr\left\{\min[\log_2(1+\gamma_{sd}^k)] < R_{tr}\right\} \tag{19}$$

where R_{tr} is the target rate, γ_{sd}^k is the received SINR at S via the selected relay R_k^*, which can be obtained by equation (8).

4 Simulation and discussions

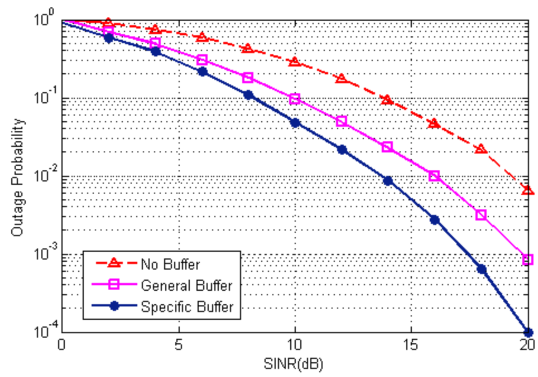
For performance evaluation, a relay-based cellular network consisting of seven hexagonal cells with a 1.6 km radius is considered. Each eNB is located at the centre of each cell, and six RNs are placed at a distance of 1.2 km from eNB with uniform angular spacing. The simulation follows the current 3GPP LTE-A evaluation guidelines in Access, EUTR (2010). Detailed simulation parameters are listed in Table 2.

Table 2 Simulation parameters

Parameters	*Values*
Carrier frequency	2 GHz
System bandwidth	20 MHz
Transmit power at eNB	46 dBm
Transmit power at RN	30 dBm
Noise power spectral density	167 dBm
RN deployment	Fixed deployment
Relay number	6 in each cell
Relay technology	Decode and Forward
Antenna configuration (at relay)	2 (1 for Tx and 1 for Rx)
Path loss model (eNB-RN)	124.5 + 37.6 log10 (d[km])
Path loss model (RN-UE)	140.7 + 36.7 log10 (d[km])
UE deployment	Uniformly deployment
Number of UE	25 UEs in each sector
Buffer size	Finite length

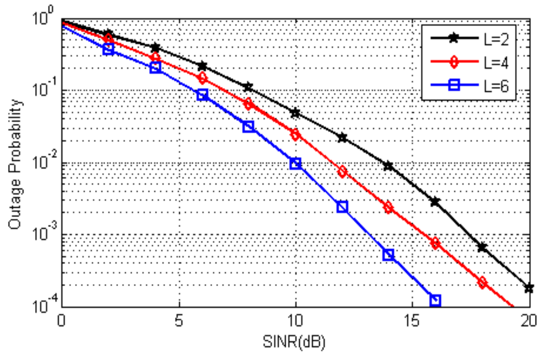
Figure 3 shows the comparison of outage probability of the proposed and other schemes. The proposed FD relay outperforms other relay protocols. In buffer-aided relaying as the transmission and reception is based on the instantaneous conditions of channel, provides better probability than FDR without buffer. In case of proposed specific buffer-aided FDR, as separate buffers are used, storing and recovering the packets become easier which leads to a well-designed buffer management than general buffer, hence the signal outage is reduced compared to other protocols.

Figure 3 Outage probability performance of different relay schemes for $L = 2$ (see online version for colours)



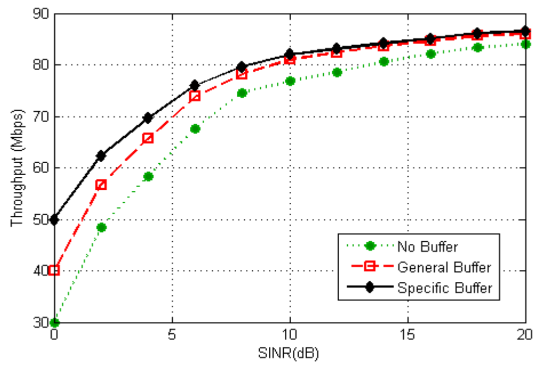
The outage probability of proposed specific buffer-aided protocol is compared with different buffer size L, whereas the buffer size increase the diversity gain increases, hence the outage probability reduces, which is illustrated in Figure 4.

Figure 4 Outage probability comparison of proposed FDR with different buffer size *L* (see online version for colours)



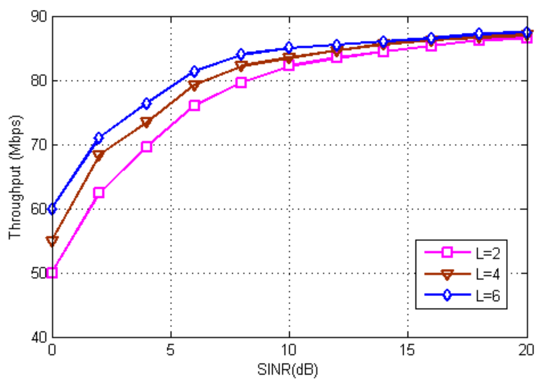
The throughput comparison of different relay protocols are depicted in Figure 5 and it is inferred that the throughput of system improves as SINR increases. In the conventional FDR protocol, the prefixed scheduling is used which leads to a significant performance degradation and reduction in throughput, due to the variation of channel link quality with time. This may prevent the relays from using the best channel links for transmitting and receiving. In the proposed FDR scheme, flexibility of the separate buffer gains the significant improvement in throughput than other schemes.

Figure 5 Comparison of throughput of different relay schemes for $L = 2$ (see online version for colours)



The throughput of the proposed relay protocol for different buffer size is depicted in Figure 6, where the system throughput increases for increasing buffer size.

Figure 6 Throughput comparison of proposed FDR for different buffer size *L* (see online version for colours)



5 Conclusions

In this paper, the use of specific buffer-aided protocol has been proposed for LTE advanced full duplexing relay network. In the proposed FD relaying, each RN has a separate buffer for storing and retransmitting data simultaneously, hence better usage of buffer is accomplished for FDR. Furthermore, the optimal trusted relay node has been selected based on both successful receiving probability with maximum instantaneous secrecy rate and the buffer state of the each RN. The estimated CSI between RN and UE is used for selection, which reduces the signalling overhead, maximises SINR, and improves the system performance. Therefore, in the proposed scheme both spectrum efficiency and QoS is achieved. The simulation results have shown that the proposed buffer-aided relay outperforms other general buffer-aided FDR and FDR without buffer schemes in terms of outage probability and throughput.

References

Access, EUTR (2010) 'Further advancements for E-UTRA physical layer aspects', Vol. 9, pp.0–0, 3GPP TR 36.814.

Akyildiz, I.F., Gutierrez-Estevez, D.M. and Reyes, E.C. (2010) 'The evolution to 4G cellular systems: LTE-Advanced', *Physical Communication*, Vol. 3, No. 4, pp.217–244.

Bulakci, Ö., Bou Saleh, A., Redana, S., Raaf, B. and Hämäläinen, J. (2013) 'Resource sharing in LTE-Advanced relay networks: uplink system performance analysis', *Transactions on Emerging Telecommunications Technologies*, Vol. 24, No. 1, pp.32–48.

Chen, C., Ji, X., Wang, J., Wang, T., Li, Y. and Wang, W. (2014) 'Full duplex with buffer-aided relay', in *Computational Science and Engineering (CSE), IEEE 17th International Conference on*, pp.1424–1429, IEEE.

Chen, K., Natarajan, B.B. and Shattil, S. (2015) 'Secret key generation rate with power allocation in relay-based LTE-A networks', *Information Forensics and Security, IEEE Transactions on*, Vol. 10, No. 11, pp.2424–2434.

Costa, A., Alfieri, A., Matta, A. and Fichera, S. (2015) 'A parallel tabu search for solving the primal buffer allocation problem in serial production systems', *Computers & Operations Research*, Vol. 64, pp.97–112.

Cui, H., Ma, M., Song, L. and Jiao, B. (2014) 'Relay selection for two-way full duplex relay networks with amplify-and-forward protocol', *Wireless Communications, IEEE Transactions on*, Vol. 13, No. 7, pp.3768–3777.

El Rhazi, A. and Pierre, S. (2009) 'A Tabu search algorithm for cluster building in wireless sensor networks', *Mobile Computing, IEEE Transactions on*, Vol. 8, No. 4, pp.433–444.

Ghosh, A., Ratasuk, R., Mondal, B., Mangalvedhe, N. and Thomas, T. (2010) 'LTE-advanced: next-generation wireless broadband technology', *Wireless Communications, IEEE*, Vol. 17, No. 3, pp.10–22.

Glover, F. and Laguna, M. (1997) *Tabu Search*, Kluwer Academic Publishers, Norwell, MA, USA.

Hoymann, C., Chen, W., Montojo, J., Golitschek, A., Koutsimanis, C. and Shen, X. (2012) 'Relaying operation in 3GPP LTE: challenges and solutions', *Communications Magazine, IEEE* , Vol. 50, No. 2, pp.156–162.

ITU (2008) 'Requirements related to technical performance for IMT-Advanced radio interface(s)', *International Telecommunications Union*.

Jin, A. L., Song, W., Ju, P. and Zhou, D. (2014) 'Energy-aware cooperation strategy with uncoordinated group relays for delay-sensitive services', *Vehicular Technology, IEEE Transactions on*, Vol. 63, No. 5, pp.2104–2114.

Kuhestani, A., Mohammadi, A. and Masoudi, M. (2016) 'Joint optimal power allocation and relay selection to establish secure transmission in uplink transmission of untrusted relays network', *IET Networks*, Vol. 5, No. 2, pp.30–36.

Li, A., Nagata, S., Harada, A. and Suda, H. (2013) 'A novel type II relay-assisted retransmission scheme for uplink of LTE-advanced system', *EURASIP Journal on Advances in Signal Processing*, No. 1, pp.1–9.

Lin, P.C., Cheng, R.G. and Chang, Y.J. (2014) 'A dynamic flow control algorithm for LTE-Advanced relay networks', *Vehicular Technology, IEEE Transactions on*, Vol. 63, No. 1, pp.334–343.

Liu, G., Yu, F.R., Ji, H. and Leung, V. (2015) 'Energy-efficient resource allocation in cellular networks with shared full-duplex relaying', *Vehicular Technology, IEEE Transactions on*, Vol. 64, No. 8, pp.3711–3724.

Loa, K., Wu, C.C., Sheu, S.T., Yuan, Y., Chion, M., Huo, D. and Xu, L. (2010) 'IMT-advanced relay standards [WiMAX/LTE update]', *Communications Magazine, IEEE*, Vol. 48, No. 8, pp.40–48.

Mukherjee, A., Fakoorian, S.A.A., Huang, J. and Swindlehurst, A.L. (2014) 'Principles of physical layer security in multiuser wireless networks: a survey', *Communications Surveys & Tutorials, IEEE*, Vol. 16, No. 3, pp.1550–1573.

Teyeb, O., Van Phan, V., Raaf, B. and Redana, S. (2009) 'Dynamic relaying in 3GPP LTE-Advanced networks', *EURASIP Journal on Wireless Communications and Networking*, Vol. 2009, No. 6, pp.1–11.

Wang, B., Zhang, J. and Host-Madsen, A. (2005) 'On the capacity of MIMO relay channels', *Information Theory, IEEE Transactions on*, Vol. 51, No. 1, pp.29–43.

Xia, X., Xu, Y., Xu, K., Ma, W. and Zhang, D. (2015) 'Practical opportunistic full-/half-duplex relaying', *IET Communications*, Vol. 9, No. 6, pp.745–753.

Yang, K., Cui, H., Song, L. and Li, Y. (2015) 'Efficient full-duplex relaying with joint antenna-relay selection and self-interference suppression', *Wireless Communications, IEEE Transactions on,* Vol. 14, No. 7, pp.3991–4005.

Yang, Y., Hu, H., Xu, J. and Mao, G. (2009) 'Relay technologies for WiMAX and LTE-advanced mobile systems', *Communications Magazine, IEEE*, Vol. 47, No. 10, pp.100–105.

Zhang, X., Shen, X.S. and Xie, L.L. (2014) 'Joint subcarrier and power allocation for cooperative communications in LTE-Advanced networks', *Wireless Communications, IEEE Transactions on*, Vol. 13, No. 2, pp.658–668.

Zhang, Z., Chai, X., Long, K., Vasilakos, A.V. and Hanzo, L. (2015) 'Full duplex techniques for 5G networks: self-interference cancellation, protocol design, and relay selection', *Communications Magazine, IEEE*, Vol. 53, No. 5, pp.128–137.

Zlatanov, N., Ikhlef, A., Islam, T. and Schober, R. (2014) 'Buffer-aided cooperative communications: opportunities and challenges', *Communications Magazine, IEEE*, Vol. 52, No. 4, pp.146–153.