Jurnal
Teknologi

Full Paper

RELAY NODE POSITIONING FOR INTER-BAND CARRIER AGGREGATION WITH ASYMMETRICAL COVERAGE

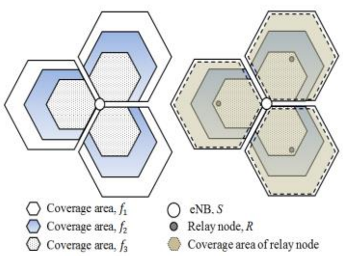
Article history
Received
17 July 2015
Received in revised form
28 October 2015
Accepted
19 January 2016

Syamsul Bahri Mohamad, Chee Yen Leow*, Tharek Abdul Rahman

Centre Wireless Communication Center, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author
bruceleow@utm.my

Graphical abstract



Abstract

Relaying and carrier aggregation are two main features for Long Term Evolution Advanced (LTE-A) that improve the signal and increase the data rate. In an inter-band carrier aggregation scenario, the use of component carriers with large frequency gaps results in asymmetrical coverage. The asymmetrical coverage leads to the capacity fairness issue, where users at the cell edge always suffer from low capacity. This paper studies the use of relay node to solve the capacity fairness issue due to asymmetrical coverage in inter-band carrier aggregation scenario with two component carrier. The effects of relay position to the capacity of cell edge user is investigated by considering various combinations of the component carrier, heights and transmit power of base station and the relay node. The simulation reveals that the relay node can be placed inside the overlapped coverage region of asymmetrical coverage in order to improve the capacity and show that for average cases the relay node should be placed close to the cell edge user.

Keywords: Relay placement; asymmetrical coverage; inter-band carrier aggregation.

1.0 INTRODUCTION

In late 2014, the Next Generation Mobile Networks Alliance (NGMN) has defined the next major phase of future wireless mobile network beyond the current 4G or IMT-Advanced standards commonly known as 5G. The 5G sets to overcome the mobile network bottleneck in terms of capacity, coverage, reliability, spectral efficiency and energy efficiency. Furthermore, 5G should support not only a massive number of users but also a massive number of devices and machines [1]. Therefore, the techniques proposed in the 4G mobile network such as relaying, carrier aggregation, coordinated multi-point transmission and reception and multiple-input and multiple-output (MIMO) have become potential features to fulfill the future demand of 5G mobile network.

This paper studies, the techniques of introducing relay node in a cell with inter-band carrier aggregation. The relay functions as an intermediate forwarding node which is placed between the base stations enhanced Node B (eNB) and the cell edge user. The relay node has the ability to extend the cellular coverage to the cell edge users who have low received signal quality [2] and to tackle the issue of the coverage hole. The infrastructure relay node is an attractive solution because it offers savings in operator's costs [3] in terms of capital expenditure (CAPEX) and implementation expenditure (IMPEX), and recurring operation expenditure (OPEX).

Meanwhile, carrier aggregation (CA) is another new future features used in LTE-A to enhance the transmission bandwidth and thus the data rate [4]. Theoretically, a wide bandwidth of transmission up to 100 MHz is obtained by aggregating two or three component carriers (CCs) belonging to contiguous or non-contiguous intra-band frequency carriers or non-contiguous inter-band frequency carriers from 450 MHz to 4990 MHz [5].

In a relay network, the physical communication links of the relay node can be classified into two. Namely the backhaul link (between eNB and relay node) and the access link (between relay nodes to user). The physical placement of relays can affect the capacity performance of users at the cell edge. Deploying a relay node far from the cell edge produces a low signal-to-noise ratio (SNR) on the access link due to large path loss. Otherwise deploying a relay node near the cell edge can reduce the signal efficiency and reduce the performance of the network and might even cause interference to the neighboring cells [6].

There are several studies related to the relay placement with different relay node deployment scenarios such as in LTE-A [7], worldwide interoperability for microwave access (WiMAX) [8], wireless sensor networks [9] as well as in WiFi access points [10]. It was suggested in [11, 12] that some of relay nodes can be placed in certain order at the cell edge to improve the coverage and to increase the capacity. A reference [13] proposes a technique based on inner and outer zone separation while [14] studies the effect of relay placement to physical layer security. In short, all researchers agreed that with the proper relay node placement, the network operator can improve coverage and enhance the capacity of the network at the cell edge. The placement of the relay node may also encounter a trade-off between the deployment cost and the cell performance gain [15]. Besides, the key benefit of relay placement research is to assist the operators in the network planning [16].

It is observed that the existing studies related to the issue of relay placement have not taken into account the feature of inter-band CA [17]. The inter-band CA is a feature in 4G that uses two or more non-contiguous frequency carriers to increase the total bandwidth of transmission to multiply the data rate. The key benefits advantage of inter-band CA is that it allows the operators to utilize segmented frequency spectrum located at different frequency bands. It also enables the flexibility of the choices of frequency bands when considering current cellular spectrum management. In inter-band CA, the asymmetrical coverage is one of the challenges since the higher frequency component carrier creates a smaller coverage radius than the lower frequency carrier because due to the fact that the path-loss increases proportionally to frequency and separation distance [18].

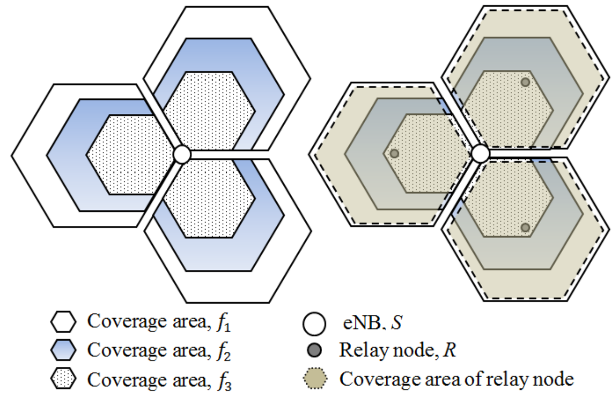


Figure 1 3-sector asymmetrical coverage of three combination bands in inter-band CA. (a) Without relaying. (b) With relay placement inside the overlapped coverage of f_1, f_2 and f_3 where $f_1 < f_2 < f_3$.

Figure 1 (a) illustrates an asymmetrical 3-sector coverage in a three component carrier inter-band CA scenario. Thus, the users who are located inside the overlapped coverage area receive a higher data rate than the users who are located outside the overlapped coverage area. Therefore, the capacity fairness for the users located inside the overlapped and non-overlapped coverage area could be lost. It motivates the use of a relay node in the asymmetrical coverage scenario to enhance the capacity of both over-lapped and non-overlapped coverage area. Figure 1 (b) illustrates the deployment of relay node inside the overlapped coverage areas of frequency carriers for f_1, f_2 and f_3 can extend the cell coverage that has been suggested as ‘Case 5’ scenario in [19].

This paper aims to investigate the effect of the position of the relay node to the overall capacity of the cell edge user inside the non-overlapped region in inter-band CA scenario. This research also studies the relay placement with different combination carriers in inter-band CA. The paper is organized by sections where Section II describes the system model, Section III describes the problem formulation while Section IV describes the simulation results and the last section concludes the paper

2.0 SYSTEM MODEL

This paper considers a one-dimensional downlink network consists of a backhaul link from base station to a relay node and an access link from a relay node to cell edge user. The cell edge user refers to cell edge located at the non-overlapped region. The same scheme is also applicable to uplink network where the user and the relay node uses the same level of transmitting power. The eNB is denoted as source S, the cell edge user at the non-overlapped area is denoted as U and relay node is denoted as R. The relay node is an in-band relay that uses single frequency carrier for backhaul link and access link to extend the coverage of the cell edge user at non-overlapped coverage area. The relay node only receives and retransmit single component carrier instead of two inter-band component carriers to reduce the complexity of relay node.

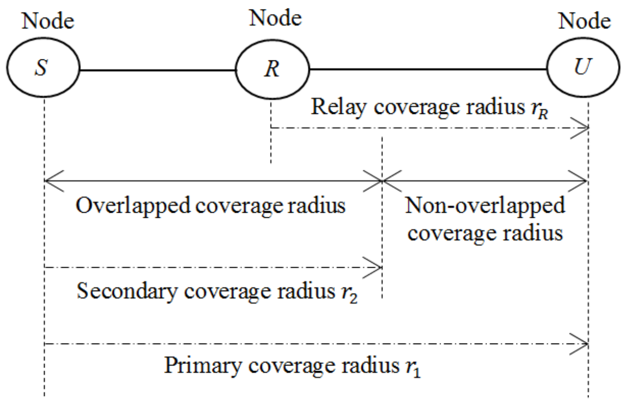


Figure 2 The coverage radiuses two hop line network scenario generated from base station$S$, and relay node R.

Figure 2 shows the one-dimensional two hop line network that illustrates two different coverage radiuses generated from a primary carrier f_1 (lower frequency) and secondary carrier f_2 (higher frequency). The size of the non-overlapped region is varying depend on the selection of component carriers in inter-band CA. The relay node R is located inside the overlapped coverage radius to forward the frequency carrier f_2 to cell edge user U at non-overlapped coverage region. To ensure the coverage of relay node R can reach the location of U, the appropriate placement of positioning of relay node R needs to be investigated due to different coverage sizes created by component carriers.

This research, a research model only considers two combinations of operating bands in inter-band CA. The scenario of the non-overlapped coverage region of two combination carriers in inter-band CA only happens when either the primary frequency carrier f_1 or secondary frequency carrier f_2 of CA are unequal, i.e. $(f_1 < f_2) \cup (f_1 > f_2)$. The frequency of the primary carrier is set to be fixed, and the frequency of secondary is varied to find out the effect of location of relay node R to the capacity of cell edge user at the non-overlapped coverage region. Both channel bandwidths for primary and secondary carriers are normalized. Theoretically $W_2 \geq W_1$ if the W_2 uses higher frequency band than W_1 [20].

Table 1 lists the notations used in this paper. This research is carried out using decode-and-forward (DF) relay scheme to communicate with cell edge user U. The relay node is an in-band half-duplex relay that uses a secondary carrier to relay a signal from base station S to user U. The separation distance between base station S and relay node R is d_α, the separation between relay node R and cell edge user U is d_β and separation distance for direct link between base station S and cell edge user U is d_i. The coverage radiuses r_1 and r_2 are produced from the same source as shown in Figure 1. Coverage radius r_R is referred to the coverage radius of relay node R.

It is assumed that the cell edge user U is located at the end of coverage radius r_2 using component carrier f_2. The terms direct link (i), relay link (j), backhaul link (α) and access link (β) are refers to the S-to-U link, S-to-R-to-U link with relay node R, S-to-R link and R-to-U link, respectively as shown in Table 1.

Table 1 List of notations

Symbol	Description
S, R, U	Wireless nodes for base station, relay, cell edge user.
f_1, f_2	Lower and higher frequency carriers.
r_1, r_2	Primary and secondary coverage radius.
r_R	Coverage radius of relay node R.
L_1, L_2	Path-loss refer to $f_1$and f_2.
W_1, W_2	Bandwidths refer to $f_1$and f_2.
α	Link between S and R (backhaul link).
β	Link between R and U (access link).
i	Link between S and U without relay (direct link).
j	Link between S and U with relay (relaying link).
d_m	Separation distance for link $m = \{\alpha, \beta, i, j\}$.
y_m, x_m	Transmit and received signal for link $m = \{\alpha, \beta, i, j\}$.
P_n	Power transmit by node $n = \{S, R\}$ per unit carrier.
C_m	Capacity for link $m = \{\alpha, \beta, i, j\}$.
C_U	Total capacity for cell edge user U.
h_m	Channel model for link $m = \{\alpha, \beta, i, j\}$.
SNR_m	Signal-to-noise ratio for link $m = \{\alpha, \beta, i, j\}$.
M_S, M_R	Maximum Allowed Pathloss for $S$and R.

In this conducted research, the received signal y_m for link $m = \{\alpha, \beta, i, j\}$ is modeled as

$$y_m = \sqrt{P_n {L_e}^{-1}} h_m x_m + z_m, \quad (1)$$

wherez_m is a complex additive white Gaussian noise (AWGN) with zero-mean and unit variance, x_m is a signal transmitted from link m with the unit transmit power of $P_n = \{P_S, P_R\}$ per single unit carrier at the base station. Here, the h_m is the small scale channel fading parameter. In this research, only line-of-sight (LOS) large scale fading is considered. Therefore, it is assumed that the $h_m = 1$ and only the path loss propagation model is captured in the analysis. In the proposed model, transmit power P_n decays with path loss, $L_e$where $L_e = \{L_1, L_2\}$. The path loss,L_e is associated with the coverage radius of any link, r_m and the frequency component carriers, f_e that will be derived in the following paragraph.

To estimate the large-scale path loss due to different propagation frequencies of the component carriers, the COST231 extension of Hata model [21] is used for frequency carriers below 2 GHz and 3GPP urban model [22] is used for frequency carrier above 2 GHz. Using the specified propagation models, the coverage radius of a base station and relay node can be estimated, and the location of relay node can be optimised to ensure the cell edge user canreceive the best capacity performance in the aggregation scenario. The omni-directional large scale path-loss models for aggregation carriers above 2 GHz is defined from 3GPP path loss urban model as

$$L_e[\text{dB}] = 36.7\log r_m - 211.3 + 26\log f_e, \quad (2)$$

where the f_e is measured in Hz and r_m is in meters. The coverage distance of this propagation model can be simplified as

$$r_m = antilog\left(\frac{L_e[\text{dB}] + 211.3 - 26\log f_e}{36.7}\right). \quad (3)$$

For the component carrier less than 2 GHz, the COST 231 Hata path loss propagation model for urban area is expressed as

$$\begin{aligned} L_e[\text{dB}] = -157.1 + 33.9\log f_e - 13.82\log h_S \\ -3.2(log(11.75h_U))^2 \\ +(44.9 - 6.55 log h_U)(log r_m - 3), \end{aligned} \quad (4)$$

whereh_S and h_U represent the height of base station and the height of receiving unit referring to the non-overlapped cell edge user. The height settings used in the COST 231 are shown in Table 2.

Table 2 The utilization of parameters for Cost 231 Hata model

Parameters	Settings
Height of base station antenna, h_S	100 m
Height of relay node antenna, h_R	10 m
Height of cell edge user, h_U	1 m

For the direct link, the COST 321 Hata urban model can be simplified by using the parameter setting shown in Table 2, as

$$L_e[\text{dB}] = -283.8 + 33.9\log f_e + 31.8\log r_m. \quad (5)$$

The coverage distance for the direct link and backhaul link COST 231 Hata urban model can be simplified as

$$r_m = antilog\left(\frac{L_e[\text{dB}] + 283.8 - 33.9\log f_e}{31.8}\right). \quad (6)$$

For access link, the COST 321 Hata urban model formulation can be expressed as

$$L_e[\text{dB}] = -289.63 + 33.9\log f_e + 38.35\log r_m. \quad (7)$$

The coverage distance of the access link using COST 231 Hata urban model can be simplified as

$$r_m = antilog\left(\frac{L_e[\text{dB}] + 289.63 - 33.9\log f_e}{38.35}\right). \quad (8)$$

In this research, the maximum coverage radius of the cell edge is determined by using the maximum allowable path loss (MAPL) [23]. The capacity of cell edge user within the non-overlapped region is determined by defining the received SNR$_m$ for link$m = \{\alpha, \beta, i, j\}$ as

$$SNR_m = \frac{|h_m|^2 \rho_n}{\Gamma L_e}, \quad (9)$$

where$\rho_n = P_n/N_0$ is defined as the ratio of transmitted power to the noise variance, with $P_n = \{P_S, P_R\}$ per single unit carrier. $\Gamma$is SNR decoding threshold corresponds to the upper bound for specific channel coding scheme [24]. In other words, the SNR$_m$ is reduced by the decoding threshold scheme and the path loss.

To establish the baseline model for the performance comparison, the link capacity of receiving node for point-to-point single antenna transmission is represented by referring to Shannon capacity theorem [21] as

$$C_m = W_e \log_2\left(1 + \frac{P_n}{N_o \Gamma \sqrt{L_e[f_e, r_m]}}\right). \quad (10)$$

The capacity of direct link C_i from base station S to the cell edge user U is given as

$$C_i = W_1 \log_2\left(1 + \frac{P_S}{N_o \Gamma \sqrt{L_1[f_1, r_i]}}\right), \quad (11)$$

where the cell edge user only receives primary component carrier f_1 because the location of cell edge user in the non-overlapped area located remotely far away from the base station and the coverage of the secondary component carrier is smaller.

During the relaying assisted transmission, the relay node Rreceives the component carrier f_2 from the backhaul link before forwarding it to the cell edge user U through the access link. Thus, the backhaul link capacity C_α from base station S to any location of relay node R is defined as

$$C_\alpha = W_2 \log_2\left(1 + \frac{P_S}{N_o \Gamma \sqrt{L_2[f_2, r_\alpha]}}\right). \quad (12)$$

It can be observed that the relay node R receives a single frequency carrier, f_2 rather than both frequencies. It can offers a low-complexity design of relay node, R. Next, the access link capacity C_β from relay node R and cell edge user inside non-overlapped area is defined as

$$C_\beta = W_2 \log_2\left(1 + \frac{P_R}{N_o \Gamma \sqrt{L_2[f_2, r_\beta]}}\right), \quad (13)$$

where relay node R uses frequency carrier f_2 to relay a signal to cell edge user located inside non-overlapped area. The achievable capacity of cell edge user U is defined as relay link capacity, C_j from base station to relay node and from relay node to cell edge user that can avoid capacity bottleneck of backhaul link and access link and can be expressed as

$$C_j = \frac{1}{2}\min\{C_\alpha, C_\beta\}. \quad (14)$$

It has been observed that the achievable relay link capacity of cell edge user U satisfies the half-duplex constraint where relay node R is unable to transmitand receive simultaneously from base station to cell edge user. The half-duplex mode requires two-time slots in relay link to communicate instead of one-time slot in the direct link. The cell edge user U uses an *orthogonal frequency-division multiplexing* (OFDM) to demodulate two different frequency carriers, f_1 from direct link i and f_2 from relay link j. Thus, the total capacity of cell edge user U can be expressed as

$$C_U = C_i + C_j. \quad (15)$$

It is assumed that the relay node receives the frequency carrier of f_2 inside the coverage distance of backhaul link with $d_\alpha \le r_1 - d_\beta$ to enable formulating the problem related to asymmetrical coverage in inter-band CA scenario. From Figure 2, the cell edge user U is located at the end of r_1 with $r_1 = d_i$where $d_i = d_\alpha + d_\beta$. The network planner can adjust the position of relay node R based on the selection of path-loss model and combination settings of aggregation carrier.

3.0 NUMERICAL SIMULATION

In this section, the downlink simulations are conducted using MATLAB to investigate the effect of relay placement for inter-band carrier aggregation scenario. For simplicity, it is assumed that component carrier f_1 is fixed, and the component carrier f_2 is varied with three different aggregation cases as shown in Table 3. These three aggregation cases represent the different frequency gaps of paired carriers in inter-band CA scenario. Comparison of those cases is carried out to reveal the effect of relay placement to the capacity. Each graph shows the potential solutions for relay placement in the asymmetrical coverage scenario.

Table 3 The utilization of simulation parameters

Parameters	Settings
Decoding threshold SNR, Γ	6 dB
Base station power transmit, P_S	46 dBm
MAPL from base station to user, M_S	145.5 dBm
Relay power transmit, P_R	26 dBm
MAPL from relay to user, M_R	119.5 dBm
Noise level, N_0	-48 dBm
Lower aggregation carriers, f_1	0.7 GHz
Higher aggregation carriers, f_2	0.8, GHz, 1.7 GHz, 3.5 GHz

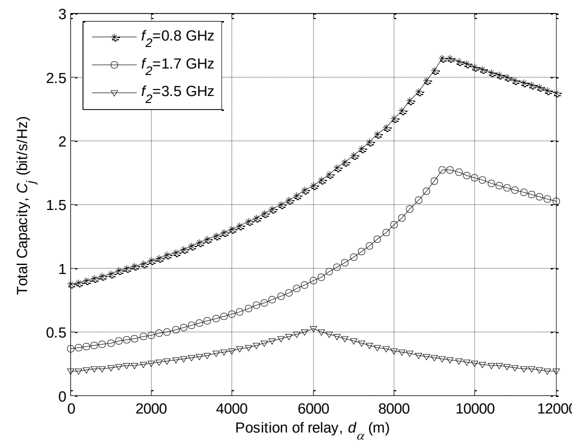


Figure 3 Relay link capacity for $P_S = P_R$and $h_S > h_R$.

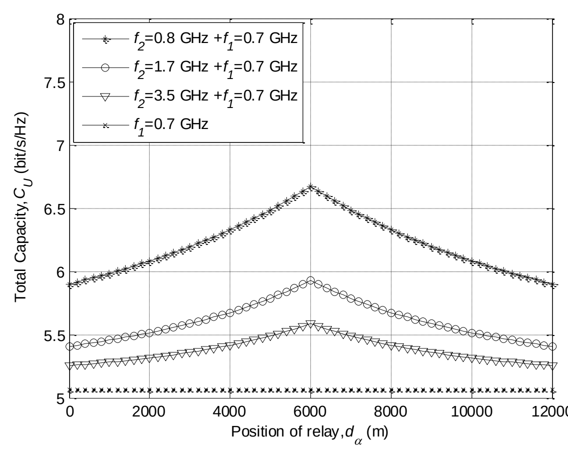


Figure 4 Total link capacity received by cell edge non-overlapped region user for $P_S = P_R = 46$ dBmand $h_S = h_R = 100$ m.

Figure 3 shows the relay link capacity of cell edge user C_j varying with the position of relay node R, d_α. In this simulation, it is assumed that the base station source S and relay node R have same link budget, i.e., $P_S = P_R$. The height of base station is higher than relay node R, i.e., h_S = 100 m and h_R = 50 m.

The maximum coverage distance of cell edge is earned by the formulation created for r_m using COST 231 Hata urban model. The result shows that the relay link capacity C_j decreases when f_2 are increased. For example at f_2 = 0.8 GHz, it shows that the maximum capacity $\overline{C_j}$ is obtained if relay node R is located at 9 km from base station S. The larger frequency gap between paired bands in inter-band CA scenario can affect the position of relay node R. When lower components carrier f_2 is used, the optimal position of relay node R is skewed toward the cell edge user U. When f_2 = 3.5 GHz (higher frequency component), the optimal location of relay node R is 6 km that is in the middle of the network between the base station and user. Overall, with the help of relay node R the capacity C_j can be increased.

Figure 4 shows the total capacity of cell edge user C_U varying with the position of relay node R, d_α, when the height of base station S and relay node R is equal, i.e., $P_S = P_R =$ 46 dBm and $h_S = h_R$ =100 m. The simulation result shows that the best position of relay node R is in the middle of the base station and cell edge at 6000 m from both nodes. The result also shows that when higher secondary aggregations are used, f_2 the total link capacity is increased. The use of the higher component carrier of with higher frequency separation gap can degrade the capacity performance. Overall, the result shows that when a relay is used to extend the coverage of the secondary carrier, the total link capacity can be increased.

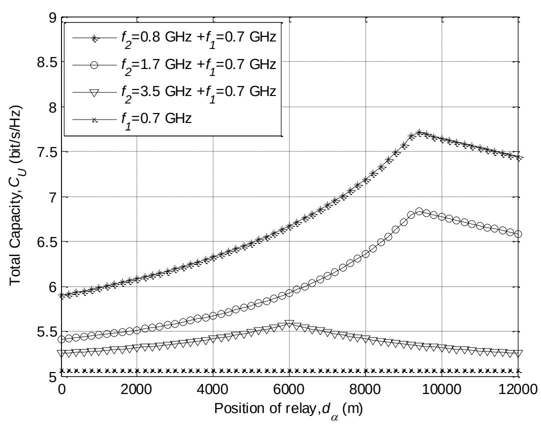


Figure 5 Total link capacity received by cell edge non-overlapped region user for $P_S = P_R = 46$ dBmand $h_S > h_R$.

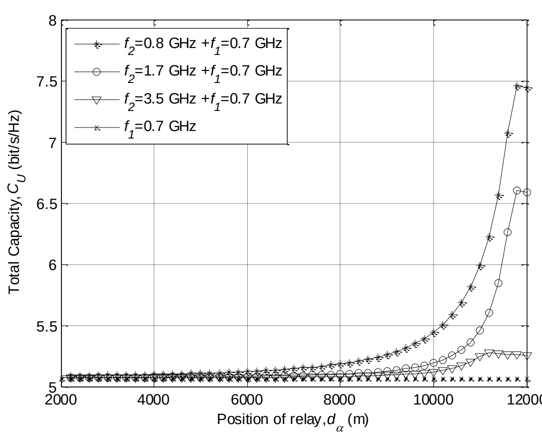


Figure 6 Total link capacity received by cell edge non-overlapped region user for $P_S > P_R$and $h_S > h_R$.

Figure 5 shows that the total capacity C_U versus the position of relay node R when the height of base station is higher than the relay node, i.e., h_S = 100 m and h_R = 50 m and the transmit power of base station and the relay node is same, i.e., $P_S = P_R =$ 46 dBm. Comparing to Figure 4, the optimal position of the relay node move towards the direction of the cell edge. The result shows when the height of base station is higher than relay node R, the total capacity C_U are increased. The result also shows the use of relay node and carrier aggregation, the capacity of the network is increased compared to direct link. Practically, the assumption of identical base station S and relay node R power i.e. $P_S = P_R$ = 46 dBm can lead to higher cost of relay node R concerning power consumption and increased interference to adjacent cells. Therefore, the reduction of P_R must be performed to reduce the power consumption of relay node R so that it can prevent the generation of interference to adjacent cells.

In Figure 6, the simulation result shows the overall capacity C_U varying with the position of relay node R, d_α against the difference setting of transmitting power and the height of base station and relay node where P_S = 46 dBm, P_R = 26 dBm, h_S = 100 m and h_R = 50 m. It is found that the total capacity of cell edge user is increase when the relay node is placed toward the cell edge starting from 6 000 m to the cell edge user U at 12 000 m. The total capacity also decreases compare to results at Figure 5 and 6 when the transmitting power for relay node is reduced from 46 dBm to 26 dBm. The result also shows that the total link capacity C_U decreases when f_2 are increased.

Table 4 Summary of findings.

Case	Parameters setting	Optimal location of R
#1	$P_S = P_R$, $h_S = h_R$	In the middle of S and U
#2	$P_S = P_R$, $h_S > h_R$	Shift right to U from #1
#3	$P_S > P_R$, $h_S > h_R$	Shift right to U from #2

In general, the optimal location of the relay node R for the cell edge user U to receive the maximum capacity C_U in case of asymmetrical coverage mainly depends on the chosen paired frequency band of inter-band CA, the transmit power of relay node P_R and base station P_S and the high of base station h_S and the height of relay node h_R. From Table 4, the parameter setting of practical cases shows that the relay node R should be placed near the cell edge in asymmetrical coverage scenario. For overall cases, the simulation results agree that the relay node R should be placed near the user cell edge to maximize the capacity of cell edge user. All the simulation agrees that with the help of relay node R, the capacity C_U can be significantly improved.

4.0 CONCLUSIONS

In this research paper, a study has been carried out to investigate the position of the relay node in a cellular network with asymmetrical coverage due to inter-band carrier aggregation. This paper determines the optimal position of the relay node in different case of scenarios. The research shows for average cases the relay node should be placed close to the cell edge user. With well-planned deployment, the capacity performance can be significantly improved. A future study should be done on how relay placement can be done with three combinations of aggregation carriers. The relay node placement research for asymmetrical coverage has a great prospect to be extended for the future research study in multi-tier 5G mobile network.

Acknowledgement

This research is supported by the Ministry of Science, Technology and Innovation Malaysia (MOSTI), the Ministry of Higher Education Malaysia (MOHE) and Universiti Teknologi Malaysia under Project Vote No. 4S079, 4F261 and 05H39.

References

[1] Mumford, R. 2015. NGMN Shares Executive Version of 5G White Paper.

[2] Iwamura, M., Takahashi, H. and Nagata, S. 2010. Relay Technology in LTE-Advanced. *NTT DoCoMo Technical Journal*. 12(2): 29-36.

[3] Lang, E., Redana, S. and Raaf, B. 2009. Business Impact of Relay Deployment for Coverage Extension in 3GPP LTE-Advanced. *ICC Communications Workshops*. 1-5.

[4] Osseiran, A., Monserrat, J. F. and Mohr, W. 2011. Mobile and Wireless Communications for IMT-advanced and Beyond. *John Wiley & Sons*.

[5] Mallison, K. 2016. 3GPP TS 36.101 V12.5.0 (2014-11) LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 12). [Online]. From : http://www.3gpp.org. [Acessed on 30 July 2015].

[6] Joshi, G. and Karandikar, A. 2011. Optimal Relay Placement for Cellular Coverage Extension. *National Conference on Communications (NCC)*. 1-5.

[7] Khakurel, S., Mehta, M. and Karandikar, A. 2012. Optimal Relay Placement for Coverage Extension in LTE-A Cellular Systems. *National Conference on Communications (NCC)*. 1-5.

[8] Chang, C. Y., Chang, C. T., Li, M. H. and Chang, C. H. 2009. A Novel Relay Placement Mechanism for Capacity Enhancement in IEEE 802.16 j WiMAX Networks. In Communications, *IEEE International Conference on Communications*. 1-5.

[9] Cheng, X., Du, D. Z., Wang, L. and Xu, B. 2008. Relay Sensor Placement in Wireless Sensor Networks. *Wireless Networks*. 14(3): 347-355.

[10] So, A. and Liang, B. 2005. An Efficient Algorithm for The Optimal Placement of Wireless Extension Points in Rectilineal Wireless Local Area Networks. *Second International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks*.

[11] Hong, W., Han, J. and Wang, H. 2011. Full Uplink Performance Evaluation of FDD/TDD LTE-Advanced Networks with Type-1 Relays. *IEEE Vehicular Technology Conference (VTC Fall)*. 1-5.

[12] Saleh, A. B., Redana, S., Raaf, B. and Hämäläinen, J. 2009. Comparison of Relay and Pico eNB Deployments in LTE-Advanced. IEEE 70th *Vehicular Technology Conference Fall (VTC 2009-Fall)*. 1-5.

[13] Basgeet, D. R. and Chow, Y. C. 2006. Uplink Performance Analysis for a Relay Based Cellular System. *VTC 2006-Spring IEEE 63rd Vehicular Technology Conference*. 1: 132-136.

[14] Mo, J., Tao, M. and Liu, Y. 2012. Relay Placement for Physical Layer Security: A Secure Connection Perspective. *IEEE Communications Letters*. 16(6): 878-881.

[15] Wang, Y., Feng, G. and Zhang, Y. 2011. Cost-efficient Deployment of Relays for LTE-Advanced Cellular Networks. *IEEE International Conference on Communications (ICC)*. 1-5.

[16] Lin, B., Ho, P. H., Xie, L. L., Shen, X. and Tapolcai, J. 2010. Optimal Relay Station Placement in Broadband Wireless Access *Networks. Mobile Computing, IEEE Transactions*. 9(2): 259-269.

[17] Mohamad, S. B., Leow, C. Y. and Rahman, T. A. 2013. Relay Placement for Inter-band Carrier Aggregation with Asymmetrical Coverage. *IEEE Symposium on Wireless Technology and Applications (ISWTA)*. 1-6.

[18] Molisch, A. F. 2007. Wireless Communications. *John Wiley and Sons*.

[19] Mallison, K. 2016. 3GPP TS 36.300 v11.5.0. Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Ac-cess Network (E-UTRAN) (Release 11). [Online]. From : http://www.3gpp.org. [Acessed on 30 July 2015].

[20] Dahlman, E., Parkvall, S. and Skold, J. 2013. 4G: LTE/LTE-Advanced for Mobile Broadband. *Academic Press*.

[21] Rappaport, T. S. 1996. Wireless Communications: Principles and Practice. New Jersey: *Prentice Hall PTR*.

[22] Mallison, K. 2016. 3GPP TR 36.814 V.9.0.0: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9). [Online]. From : http://www.3gpp.org. [Acessed on 30 July 2015].

[23] Holma, H. and Toskala, A. 2012. LTE Advanced: 3GPP Solution for IMT-Advanced. *John Wiley and Sons*.

[24] Tse, D. and Viswanath, P. 2005. Fundamentals of Wireless Communication. Cambridge *University Press*.