

Performance Enhancement for LTE-A Networks Using Small Nodes

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Abstract—Long Term Evolution- Advanced (LTE-A) is the succeeding version of LTE system to enhance capacity and coverage. Multi-hop relay is one of technologies supported by LTE-A, which aims to enhance the cell-edge capacity. Multi hop technologies are categorized into a fixed relay node (FRN) and a moving relay node (MRN). This paper proposes a system model, which improves the capacity and throughput by employing moving and fixed relay coupled with half-duplex mode. It was expected that the MRN installed on the top of vehicles improves the capacity and throughput for vehicular users when the vehicles move at high speed, while FRN deployed far from BS enhances the coverage at cell edge. Amplify and forward (AF) and decode and forward (DF) protocols were used with these two types of relays. Furthermore, the relay channel and amplification gain were derived in this paper to get the maximum advantage via multi-hop technology. Simulation and analytical results show an increase in the throughput from 1.8Mbps to 3.7Mbps for 35 users after employing the MRN on moving vehicle. Furthermore this value improved to 4.1Mbps after employing the MRN within a LTE-A cell coupled with FRNs deployed around BS, according to the proposed location.

Index Terms—AF Relay; DF Relay; Moving Relay Node; Long Term Evolution- Advanced, LTE-A.

I. INTRODUCTION

The 3GPP- LTE is a standard developed by 3GPP to handle the increasing data rate and coverage extension. LTE is an evolution of 3G systems and supply of quality levels, which are the same as the current wired networks. At the cell boundaries, the capacity and throughput remain small due to the low signal to noise ratio (SNR). Thus, the LTE-A was developed with the aims to improve LTE features in terms of throughput and capacity. Relay is a function considered in LTE-A to enhance the cell-edge capacity and allow the use of network resources efficiently [1]. Lately, multi hop relaying has become one of interesting technologies, which is related with LTE-A networks. Dense infrastructure servers can be achieved by deploying the relay nodes in a manner, which minimizes the path distance between the sender and the destination, thereby providing higher data rates. Relay technologies outperform in cellular networks even in highly shaded environments, where signals suffer fading by enhancing the throughput and cell capacity [2]. Relay Nodes can be deployed to expand LTE coverage in rural areas at low cost. Relay Nodes has lower power than the BS that provides enhanced throughput at the cell edges.

The emergence of Vehicular User Equipment (UEs), which are mostly smart phones and tablets resulted in the demand for high volumes of wireless traffic data due to the accessed

services and applications. However, this expectation cannot be satisfactorily met by the current architecture, where each UE communicates directly with the eNB. Moving RNs (MRN) have recently attracted research interest [3],[4] with a view to extend cellular coverage and improve the receipt of signals at vehicular UEs. LTE release-10 standard supports nomadic RN, and the support for mobility has been investigated by the 3GPP TR 36.836 Technical report [5],[6]. High-speed vehicles present wireless communication challenges between on-board UE and eNB in the form of vehicle penetration loss (VPL) and Doppler shift. Exterior antennas mounted on a vehicle can be used for backhaul link communication (RN to DeNB), and then connected to interior antenna, which will provide access link communication (UE to RN). This connection is made to overcome VPL [7].

In LTE-A, a relay node (RN) is connected to a donor eNB (DeNB) in either an in-band or out-of-band wireless backhaul. The RN operates its own cell and appears to UEs as a normal eNB. Studies have proved that there are gains in the coverage and the capacity through the deployment of fixed RNs [8]–[10]. Further, technical details are given for relay nodes in [11]

A relay node amplifies signals received from the sender and then retransmits these signals to destination(s) in order to increase the capacity and extend the coverage of cellular systems. The relay link (RL) is wirelessly connected to base stations (BS), while access link (AL) is wirelessly connected to users. The LTE conventional cellular networks cover around 2–5 km as diameter, while, a relay node will only cover a region of diameter 200–500 m. This means that the transmit power spent by relay node is significantly lower compared to BS. RN can operate in half-duplex (HD) mode (i.e., they transmit and receive signal with different time slots) or in full-duplex (FD) mode.

Different types of small cell nodes, such as pico cells, fixed relay nodes, moving relay nodes (MRNs), and home base station are illustrated in Figure 1. These small cell nodes are deployed based on the underlying BS to either enhance throughput or increase network capacity. The network structure adds relay nodes to the network architecture and allows traffic/signaling forwarding between the users and the central station to increase coverage around cell boundaries and in high-shadowing environments between buildings. In addition, the relay structure enhances the capacity in hotspots shown in Figure 1[12].

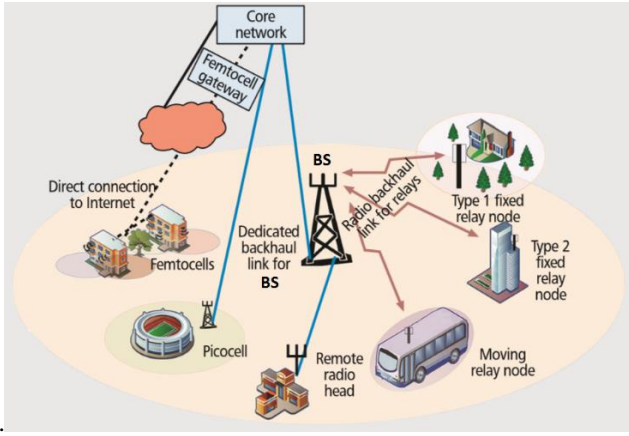


Figure 1: Multi-hop relay technologies through LTE-A networks

II. RELAY TRANSMISSION STRATEGIES

In this paper, two-hop technology between BS and UE units via RN, employing different transmission schemes is created. The relay node is categorized into two types according to signal processing, scheduling and security issues.

Amplify and Forward (AF): It is a type of repeater, where RN receives the signal from BS (or UE), and forwards it to UE or BS after the amplification. AF relay are beneficial, although most of the noise-limited system have short delays. AF relays amplify interference and noise as shown in Figure (2-a) [13].

Decode and forward (DF): In DF relays, a new signal is forwarded after encoding the desired signal although there is a long delay processing [12]. DF relays amplify signals but cancel the noise and interference, as in the case with the AF relay as shown in Figure (2-b)[13]. In this work, half-duplex system is proposed with two different scenarios.

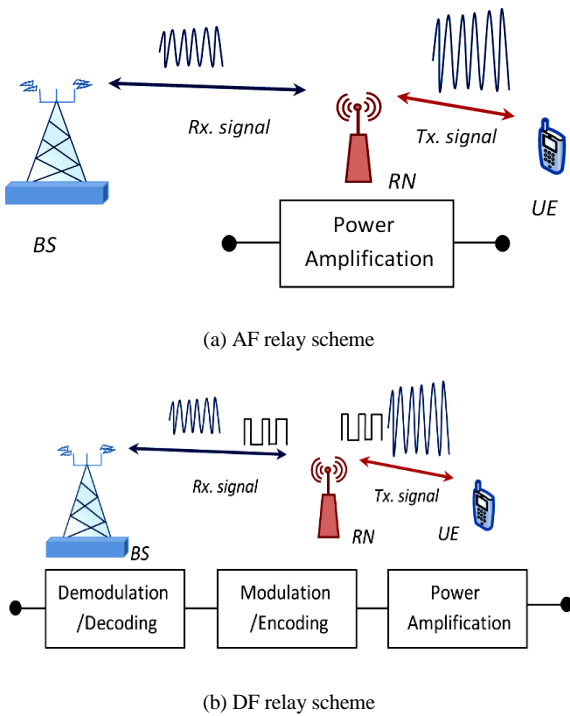


Figure 2: Relay types according of signal processing

III. SYSTEM MODEL

This paper proposes a system model coupled with three wireless small nodes, a source represented by BS, intermediate

station is the relay node (RN) and the destination is UE, therefore the received signal at UE is:

$$y(t) = hx(t) + \sigma(t) \quad (1)$$

where $x(t)$ represents transmitted signal from BS, h is the channel between source and destination, and $\sigma(t)$ represents symmetric additive white Gaussian noise (AWGN) with variance σ [i.e., $n \sim CN(0, \sigma)$] [14].

A. Fixed node scheme

This system suggests that relay and UE are fixed, considering the half duplex system. In time slot $[t_1]$, BS transmits its information to both UE and RN. The received signals at the uplink $y_{RN}[t_1]$, at the downlink $y_{UE}[t_1]$, at the relay and their destinations can be written as follows:

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

$$y_{UE}[t_1] = h_{DL}x[t_1] + \sigma[t_1] \quad (3)$$

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

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

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

Forward signal for a simple AF relay can be derived with fixed-gain amplification of the original transmit signal as shown in Equation (6), where g_{AF} is the amplification gain, keeping the power level of relay in account .

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

P_{BS} is the transmitted powers from the BS, P_{RN} is the transmitted powers from the relay node, whereas σ_{RN} represents the variance of the relay noises.

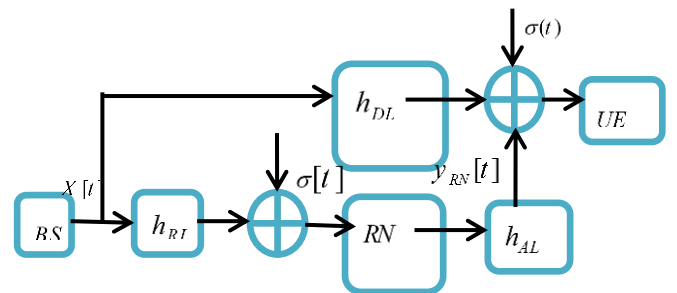


Figure 3: Relay channel model

Figure 3 shows a relay channel with a slow and flat fading radio. In the half duplex model, channel gains and noises should not change from both time slots $[t_1]$ and $[t_2]$. The matrix form between the source $i = BS$ or MRN and destination; $j = MRN$ or UE can be expressed as:

$$\underbrace{\begin{bmatrix} y_{UE}[t_1] \\ y_{UE}[t_2] \end{bmatrix}}_{\mathbf{y}_{UE}} = \underbrace{\begin{bmatrix} h_{DL} & 0 \\ h_{DL}g_{AF}h_{RL} & h_{DL} \end{bmatrix}}_{\mathbf{H}} \begin{bmatrix} x[t_1] \\ x[t_2] \end{bmatrix} + \underbrace{\begin{bmatrix} \sigma \\ h_{AL}g_{AF}\sigma_R \end{bmatrix}}_{\boldsymbol{\sigma}}$$

The mutual information of AF-relaying is defined in Equation (6) [15]:

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

where \mathbf{H} represents channel matrix, while I stand for identity matrix.

B. Mobility Node Scheme

One promising solution is to install MRN, on a public moving vehicle to serve the passengers. An MRN can eliminate vehicular penetration loss that affects wireless services. Moreover, MRNs can use smart antenna techniques and advanced signal processing schemes. In this scheme, we suggest a MRN installed on top of the vehicle, and it intermediates between UE and BS, where UE moves with velocity (\mathbf{v}_{RN-UE}) around MRN via access link. d_{RN} is the radius that demonstrates an access link. The direct link between BS and UE (d_{UE}) is the distance that alters with the movement of UE. In addition, the MRN moves away from BS with a straight movement between the points (A and B), where d_{BS} is the distance between the base station and the moving relay node, as shown in Figure 4.

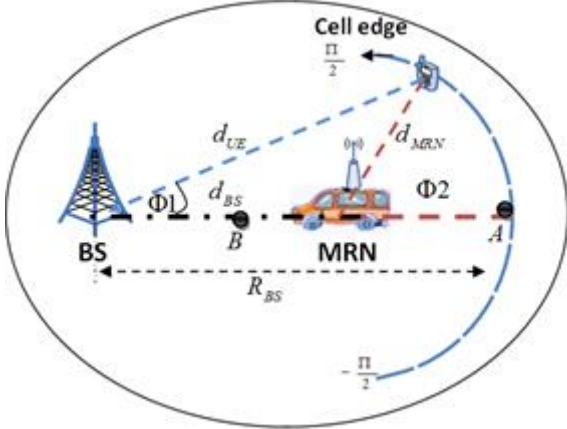


Figure 4: MRN Architecture with distances between hops

The throughput and capacity are influenced by the channel fluctuations, as shown in the expression [16].

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

where $G = G_t G_r h_t^2 h_r^2$, $G_t(h_t)$ represents antenna gain and height of transmitter, $G_r(h_r)$ represents antenna gain and height of receiver, d represents distance between the sender, and destination a (typically $\in \{2 - 5\}$) [16].

The velocity of UE nearby RN is defined as:

$$v_{MRN-UE} = d_{MRN} \frac{\Delta\phi_2}{\Delta t} \quad (11)$$

The velocity of UE toward BS is defined as:

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

The velocity of MRN to BS can be expressed as:

$$v_{BS-MRN} = \frac{(A-B)}{t_{BS-MRN}} \quad (13)$$

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

where t_{BS-MRN} stands for RN driving time from MRN to BS.

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

and

$$d_{MRN} \leq R_{MRN}, \quad d_{BS} \leq R_{BS}$$

where R_{BS} and R_{MRN} are the maximum coverage radio for BS and the relay.

Equations (2), (3), and (4) can be expressed as:

$$y_{MRN}[t_1] = G_1(v_{BS-MRN} T_{BS-MRN})^{-\alpha} x[t_1] + \sigma_{MRN}[t_1] \quad (14)$$

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

at the second slot t_2 ,

$$y_{UE}[t_2] = G_2(v_{BS-UE} T_{BS-UE})^{-\alpha} x[t_2] + \quad (16)$$

$$G_2(v_{MRN-UE} T_{MRN-UE})^{-\alpha} x_{MRN}[t_2] + \sigma_{UE}[t_2]$$

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

Source $a = BS$, RN , and destination $b = RN$, UE received SNR (ρ) can be penned as:

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

The half-duplex limitation disturbs the multi-hop improvement, such that if $\rho_{RL} \gg \rho_{DL}$ and $\rho_{AL} \gg \rho_{DL}$, the relay provides a good link since it contains more and better antennas to achieve diversity than the direct link. Therefore, the capacity with DF relay turns into:

$$C_{DF} = \frac{B}{2} \min \left\{ \log_2 \left(1 + 2 \left(\frac{|G_1(v_{MRN-UE} T_{MRN-UE})^{-\alpha}|^2 P_{MRN}}{\sigma_{MRN} B} \right) \right), \right. \quad (18)$$

$$\left. \log_2 \left(1 + 2 \left(\frac{|G_2(v_{BS-MRN} T_{BS-MRN})^{-\alpha}|^2 P_{BS}}{\sigma_{UE} B} \right) \right) \right\}$$

IV. RESULTS AND DISCUSSION

In this section, simulations were conducted to analyze the attainable capacities of relaying in two different formations for half-duplex (AF and DF) with simulation parameters used in [4].

For the first and second schemes, Figure 5 shows SNR versus the spectral efficiency of the relay link. It has been proved from the simulation results that SNR for the DF relay outperformed AF relay. Figure 6 demonstrates the graph between the transmitted power by BS with the spectral efficiency, where the spectral efficiency increases when the transmitted power rises. Figure 7 explains the performance of two-ways UL and DL of both AF and DF relay. The performance of relay placement is evaluated by two-way bit rate, where the transmitted power of the UE is lower than the powers of the relay and BS, since the RN and BS have more antennas than the UE. The optimal placement for AF relay is 70% from the coverage radius of the cell at the DL and UL. Whilst the optimal location for DF relay is 50% from the coverage cell radius since the AF relay has amplification gain factor larger than DF relay. Figure 6 describes the locations for the two relays to gain the maximum rate.

Figure 8 shows the spectral efficiency and the receive SNR of the relay link (RL). The spectral efficiency of HDX AF relaying is higher than the spectral efficiency of HDX DF relaying and the spectral efficiency of FDX AF relaying outperforms on the FDX DF. This shows that the relay link quality on DF relay is better than RL in AF relay, means relay link is powerful and DF relay overcomes AF behavior in spectral efficiency.

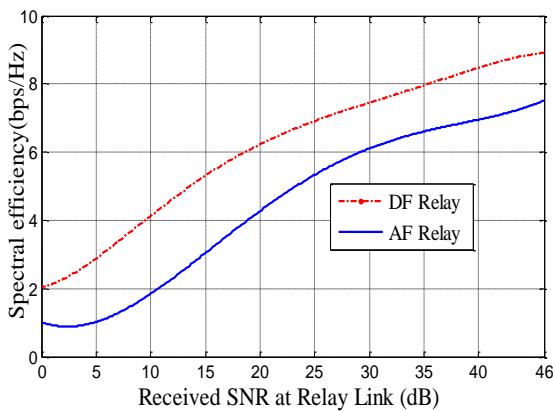


Figure 5: Relationship of capacity and received SNR at Access Link for AF and DF Relays

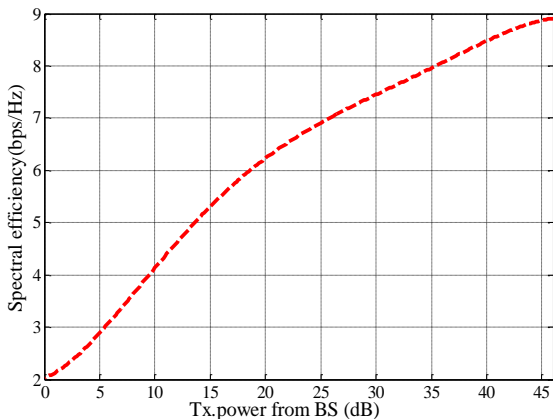


Figure 6: Capacity versus P_{BS} in the downlink transmission

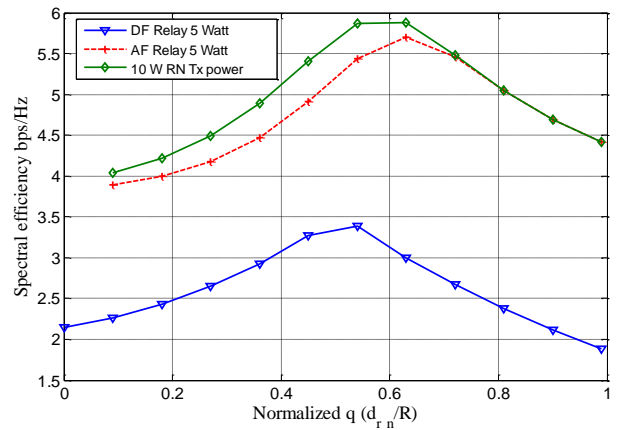


Figure 7: The optimal placement for DF and AF relay

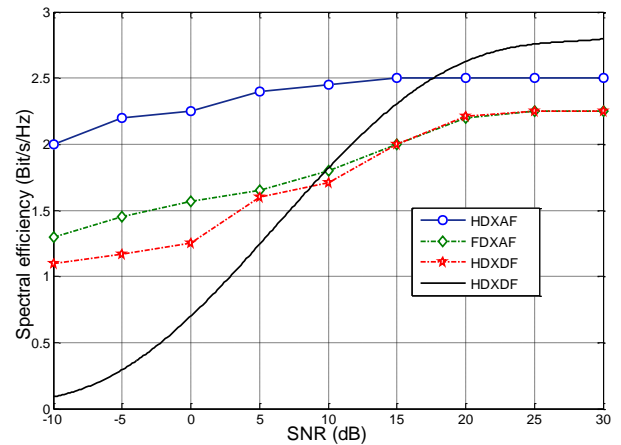


Figure 8: Relationship of Spectral efficiency and receive SNR of Relay Link: HDX AF, FDX AF, HDX DF and FDX DF

Figure 9 describes the increasing numbers of active users by installing MRN on the top of moving vehicle as MRN amplifies the received signal from BS and retransmits it to passengers with an amplification factor. For instance, the throughput for 35 users rose from 1.8Mbps to 3.7Mbps after using MRN on the top of the vehicle. This value increased to 4.1Mbps after using MRN within a LTE-A cell, which contained FRNs deployed around BS according to the proposed location. This enhancement provides a good mobile service for passengers and avoids any interruption in service for high speed vehicles (i.e. buses or trains).

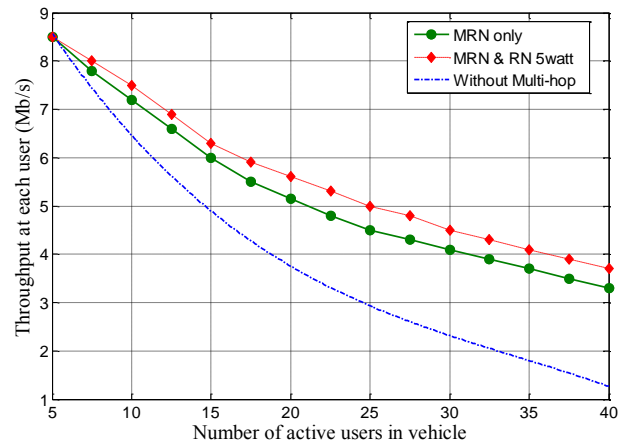


Figure 9: Enhancement in Throughput for users linked with MRN

V. CONCLUSION

This work has investigated the downlink performance enhancements by employing Multi-hop Relay technology based on two schemes. In the first method, all nodes were fixed with AF and DF relays with optimal placement. In the second scheme, MRN installed on top of moving vehicles, to enhance the capacity and throughput for vehicular users when the vehicles moves with high speed. This work described the effect MRN installation on the top of vehicle such as bus or train where the MRN increased the throughput of the users inside the vehicle. This paper investigated the capacity relationship with SNR employing different transmission mode to provide the maximum capacity with low cost.

REFERENCES

- [1] J. Parikh and A. Basu, "LTE Advanced The 4G Mobile Broadband Technology," *Int. J. Comput. Appl.*, vol. 13, no. 5, pp. 17–21, 2011.
- [2] J. A. Aldhaibani, A. Yahya, R. B. Ahmad, R. A. Fayadh, and A. H. Abbas, "Reducing Transmitted Power Of Moving Relay Node In Long-Term Evolution-Advanced Cellular Networks," vol. 10, no. 6, pp. 1051–1061, 2014.
- [3] Y. Sui, Z. Ren, W. Sun, T. Svensson, and P. Fertl, "Performance Study of Fixed and Moving Relays for Vehicular Users with Multi-cell Handover under Co-channel Interference," 2013.
- [4] A. Aneja, "Review on Moving Relay Nodes in LTE-Advanced," vol. 2, no. 6, pp. 1–3, 2014.
- [5] Simon Scott et. al., "A Cooperative Moving Relay Node System Deployment In A High Speed Train " Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th.
- [6] A. Yahya, J. A. Aldhaibani, R. B. Ahmad, J. Chuma (2017) "LTE-A Cellular Networks: Multi-hop Relay for Coverage, Capacity and Performance Enhancement" Springer International Publishing AG, Gewerbestrasse 11, 6330 Cham, Switzerland.
- [7] S. Scott, J. Leinonen, P. Pirinen, J. Vihri, P. O. Box, and F.- Oulu, "A Cooperative Moving Relay Node System Deployment In A High Speed Train," 2013.
- [8] D. Liu, Y. Chen, and T. Zhang, "Procedia Engineering Research on Cooperative User Relaying Assisted Load Balance Scheme in OFDMA Networks," vol. 29, pp. 3799–3807, 2012.
- [9] A. Alizadeh, "Analysis of coverage region for MIMO relay channel Analysis of Coverage Region for MIMO Relay Channel," no. August 2016, 2012.
- [10] M. Badar and N. Maqbool, "Adaptive Relay Protocol Based on Relay Node Location," vol. 3, no. 9, pp. 1–4, 2012.
- [11] M. Iwamura, H. Takahashi, and S. Nagata, "Special Articles on LTE-Advanced Technology — Ongoing Evolution of LTE toward IMT-Advanced — NTT DOCOMO Technical Journal Relay Technology in LTE-Advanced," vol. 12, no. 2, pp. 29–36.
- [12] C. Hoymann, "Relaying Operation in 3GPP LTE-Challenges and Solutions," no. February, pp. 156–162, 2012.
- [13] J. Al-dhaibani, A. Yahya, R. Ahmed, and A. Zain, "Performance Enhancement of LTE-A, a Multi-Hop Relay Node, by Employing Half-Duplex Mode," *RN*, vol. 9, no. 3, pp. 73–78, 2012.
- [14] A. Aldhaibani, A. Jaafar;Ahmad, Badlishah, R.;Yahya and R. B. Ahmad, "Performance Analysis of Amplify and Forward Relay during Uplink and Downlink in LTE-A Cellular Networks," no. JANUARY, 2014.
- [15] R. U. Nabar, H. Bolcskei, and F. W. Kneubuhler, "Fading Relay Channels: Performance Limits and Space–Time Signal Design," *IEEE J. Sel. Areas Commun.*, vol. 22, no. 6, pp. 1099–1109, 2004.
- [16] N. Krishnan, R. D. Yates, N. B. Mandayam, and J. S. Panchal, "Bandwidth sharing for relaying in cellular systems," *IEEE Trans. Wirel. Commun.*, vol. 11, no. 1, pp. 117–129, 2012.