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PERFORMANCE ANALYSIS OF TWO-WAY MULTI-USER WITH BALANCE TRANSMITTED POWER OF RELAY IN LTE-A CELLULAR NETWORKS

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ABSTRACT

Wireless multi-hop relay systems have become very important technologies in mobile communications. These systems ensure high-speed data transfer and extended coverage area at a low cost. In this paper, we proposed two scenarios. In the first scenario we studied the performance of a two-way multi-hop relay network and proposed a half-duplex mode amplify-and-forward relay with two cases. In the first case, we studied a fixed relay node (FRN) with (q^{th}) users for two-way performance keeping user equipment (UE) is fixed and is moving at different velocities toward FRN. In second case, we proposed a new connection between the (k^{th}) moving relay nodes (MRN) and users had the same the velocities and times, in which users are independently moving between them. In the second scenario the balanced power algorithm for MRN is proposed, this algorithm is control of the transmitted power over cell radius to achieve the required SNR and throughput at the users with reducing the consumption transmitted relay power. Is has been shown from the simulation results that there is saving nearly 75% from transmitted power after using proposed algorithm.
Keywords: *AF relay, LTE-A, half-duplex, velocity*

1. INTRODUCTION

Long-term evolution-advanced (LTE-A) is the successor of the 3rd generation partnership project (3GPP) LTE, which is expected to improve LTE features in terms of coverage and throughput [1]. The relay is one of the main innovations of LTE-A, which improves the cell-edge coverage throughput and increases the usage efficiency of network resources. The basic idea of the relay is that the signals are forwarded by one or more relay nodes (RNs) before retransmitting to the destination node rather than the base station (BS) directly sending signals to user equipment (UEs).

The relay structure adds relay nodes to the network architecture and enables traffic/signalling forwarding between the UE and the BS to expand the coverage around cell edges and in high-shadowing environments. In addition, the relay structure increases the capacity in hotspots [Figure 1.];[2].

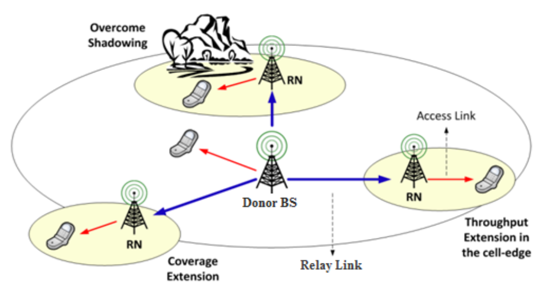

Figure 1 Relaying scenarios

Researchers continue to look for ways to improve network throughput and coverage due to the demand for mobile Internet and wireless multimedia applications, as well as the requirements for future 4G systems. The search for low-cost resources is the first step to meet these goals, and low-cost relay stations (RNs) in each cell are being deployed in next-generation cellular systems. The RNs increase the cell radius, because the RNs are closer to the cell edge UEs than the BSs. Furthermore, RNs improve the received signal-to-noise ratio (SNR) to UEs. The

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infrastructure cost of distributing more BSs is reduced because the cell radius is increased.

The RNs are wirelessly connected to the radio access network via a donor cell, which is connected to the donor BS by a relay link. The UEs are connected to the RN via the access link, as shown in Figure 1. Based on the spectrum obtained for the access and relay links, relaying can be classified into out-band and in-band types. In out-band relaying, the relay link operators are used in a spectrum that is different from that of the access link operators. On the other hand, the in-band relaying relay and access links operate in the same spectrum, where the links share other mechanisms to avoid interference between the access and relay links and deal with the half-duplex mode as detailed in this paper [2, 3, 4].

The relay is the intermediate node between the source and destination, that receives the RF signals from the donor, processes them, and then re-sends them to the various destinations [5]. Based on this processing, the relay can be classified into two types:

- Layer 1 relay, which is also called the amplify-and-forward (AF) relay, amplifies the receiving signal before forwarding it to the destination. However, the noise and interference are also amplified along with the desired signal with a relatively small time delay. We focused on this type in this paper.
- Layer 2 relay involves decode-and-forward operations, through which the data packets are obtained from the RF signals, processed, regenerated, and then forwarded to the next hop. This kind of relay can eliminate interference and noise but creates more delay [8].

Two types of relaying behavior can be observed, namely, fixed relay node (FRN) and moving relay node (MRN). FRNs are deployed by users in a more peremptory manner, e.g., in coverage holes, whereas MRNs are mounted on transportation vehicles such as buses, trains, and riverboats to provide higher throughput and lower handover interruption for passengers, as shown in Figure 2.

In this paper, we investigated and analyzed MRNs in the same cell with low delay and two-way transmissions (uplink and downlink) against users who are moving at non-uniform velocities.

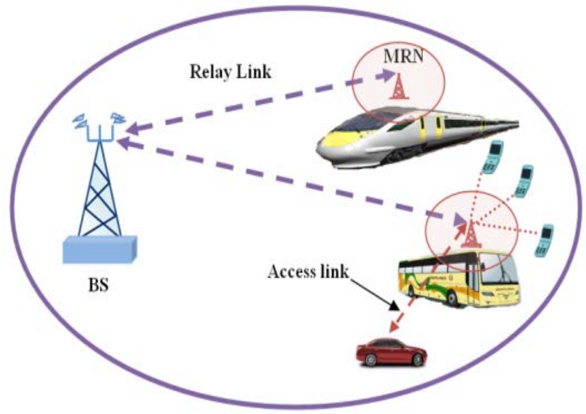

Figure 2. Several application scenarios for moving relays

The rest of the paper is organized as follows: Section 2 presents the proposed system mode and describes the first scenario of the multi-user with multi MRNs. Section 3 we explain the Power-Balancing Algorithm for UE .Section 5 discusses the results of the proposed model, and Section 6 concludes this paper

2. SYSTEM MODEL

We studied a conjunct system with three wireless nodes, namely, a source BS, RN, and UE, as shown in Figure 2, with the received signal

$$Y = HX + n \tag{1}$$

where X is the transmitted symbol from BS, H is the coefficient channel between the source and the destination, and n is the additive circularly symmetric White Gaussian Noise (AWGN) in the corresponding channels with variance N_O i.e., n ~ CN (0, N_O) [9].

2.1 Multi-user with relay node performance

- Fixed node scheme

In the first case for this scenario, we set the BS, RN, and UEs, as $\boldsymbol{Q} = \{UE_1,\ UE_2,\ \cdots UE_q\}$ as fixed. The suggested system was considered to operate in a half-duplex mode, where the relay cannot simultaneously transmit and receive. In time slot $[t_1]$ the relay receives information from both the BS and UEs, as shown in Figure 3. The received signal, $\mathrm{y}_{\mathrm{RN}}[t_1]$ can be written as

$$\mathrm{y}_{\mathrm{RN}}[t_1] = H_A X[t_1] + \sum_{q=1}^{\mathrm{Q}} H_{B,q} X[t_1] + n_{RN} \tag{2}$$

where q=1, 2, 3…Q, Q is the total number of UE

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and n_{RN} is the AWGN with variance N_{O}. The received signal at UE from BS via a direct link is

$$\mathrm{y}_{\mathrm{UE,q}}[t_1] = H_{C,q}X[t_1] + n_{UE}[t_1] \tag{3}$$

At the second slot $[t_2]$, the BS and $\mathrm{UE_q}$ receive the amplified signals transmitted from RN, $X_{RN}[t_2]$, with amplification factor η [8].

$$\eta_q = \sqrt{\frac{P_{RN}}{P_{BS}\,|H_A|^2 + P_{UE}\,|H_{B,q}{}^2 + N_{\mathrm{O}}}} \tag{4}$$

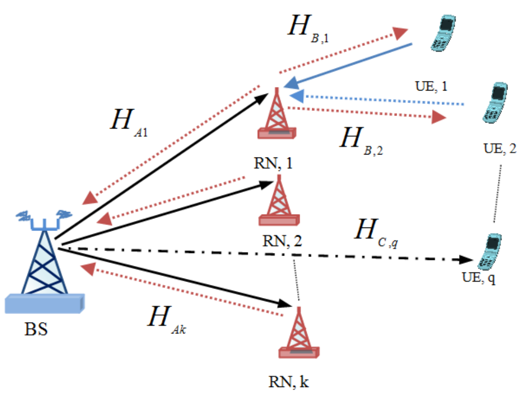

Figure 3 Half-duplex Relay scheme

The uplink transmitted signal from the relay to the base station can be represented as

$$\mathrm{y}_{\mathrm{BS}}[t_2] = \eta H_A \mathrm{y}_{\mathrm{RN}}[t_1] + n_{BS} \tag{5}$$

$$\mathrm{y}_{\mathrm{BS}}[t_2] = \eta\left[H_A X[t_1] + \left(\sum_{q=1}^{\mathrm{Q}} H_{B,q}X_q[t_1]\right) + n_{RN}\right] + n_{BS} \tag{6}$$

uplink transmitted signal from the relay link and direct link to the base station can be represented as

$$\mathrm{y}_{\mathrm{BS}}[t_2] = \underbrace{\left(\sum_{q=1}^{\mathrm{Q}} H_{B,q}X_q[t_2]\right)}_{\text{Direct link}} + \underbrace{\eta H_A H_A X[t_1] + \left(\eta H_A \sum_{q=1}^{\mathrm{Q}} H_{B,q}X_q[t_1]\right) + \eta H_A n_{RN} + n_{BS}}_{\text{Relay link}}$$

The downlink second way transmitted signal from the relay and direct link to $\boldsymbol{Q}^{th}$-users can be represented as

$$\mathrm{y}_{\mathrm{UE,q}}[t_2] = H_{C,q}X[t_2] + \eta H_{B,q}\mathrm{y}_{\mathrm{RN}}[t_1] + n_{UE} \tag{7}$$

$$\mathrm{y}_{\mathrm{UE,q}}[t_2] = H_{C,q}X[t_2] + \eta H_A H_{B,q}X[t_2] + \left(\eta H_{B,q}H_{B,q}X[t_2]\right) + \eta H_{B,q}n_{RN} + n_{UE}$$

where n_{BS} and n_{UE} are the AWGNs with variance N_{O} at the BS and $\mathrm{UE_q}$, respectively.

Each source node processes and cancels the self-interface term from the received signal [9,10]. Therefore, the resulting signals at BS and $\mathrm{UE_q}$ can be rewritten as

$$\hat{y}_{\mathrm{BS}}[t_2] = \left(\sum_{q=1}^{\mathrm{Q}} H_{C,q}X_q[t_2]\right) + \left(\eta H_A \sum_{q=1}^{\mathrm{Q}} H_{B,q}X_q[t_1]\right) + \eta H_A n_{RN} + n_{BS} \tag{8}$$

In addition, the signal at each q-user can be expressed as

$$\hat{y}_{\mathrm{UE,q}}[t_2] = H_{B,q}\; X[t_2] + \eta_q H_A H_{B,q} X[t_2] + \eta_q B_{RN-UE} n_{RN} + n_{UE,q} \tag{9}$$

Assuming that the noise (AWGN) at all sources is equal $(n_{RN} = n_{BS} = n_{UE} = N_o)$, based on the above analysis, we can evaluate the instantaneous SNR in two ways (downlink and uplink) respectively as follows:

$$\rho_{UE,q} = \frac{P_{BS}\,|H_{B,q}|^2}{N_{\mathrm{O}}} + \frac{\eta^2 P_{BS}\,|H_A|^2 |H_{B,q}|^2}{\left(\eta^2\,|H_{B,q}|^2 + 1\right)N_{\mathrm{O}}} \tag{10}$$

$$\rho_{BS} = \frac{\sum_{q=1}^{Q} P_{UE}\,|H_{C,q}|^2}{N_{\mathrm{O}}} + \frac{\eta^2 P_{UE}\,|H_A|^2 \sum_{q=1}^{Q} |H_{B,q}|^2}{\left(\eta^2\,|H_A|^2 + 1\right)N_{\mathrm{O}}} \tag{11}$$

- Mobility nodes scheme

In the section, we proposed a mobility model with a half-duplex mode and an AF two-way relay. All UEs moved toward the RN at equal and different velocities. The performance and impact on user velocity on the SNR were analyzed within a two-way relay.

The SNR is affected by the channel environment such as the distance between the transmitter and receiver, the fading state of the channel, and noise and interference [11]. Thus, the channel coefficient between the source and the destination can be defined as

$$\left|H_{i-j}\right|^2 = L(d)^{-\alpha} \tag{12}$$

Where $L = G_t G_r h_t{}^2 h_r{}^2, (G_t, h_t)$, and (G_r, h_r) are the gains and heights of the transmitter and receiver antennas, respectively, whereas d is the distance between the source and destination. α (typically $\in \{2-5\}$) is the path-

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loss exponent, which is dependent on the environment [12,14].

In the relay strategy, the SNR at the relay link is much greater than the SNR at the direct link. Therefore, we can neglect the direct link part in (10).

$$\rho_{UE,q} = \frac{\eta^2 P_{BS} |H_A|^2 |H_{B,q}|^2}{\left(\eta^2 |H_{B,q}|^2 + 1\right) N_O} \quad (13)$$

Inserting (4) in (13), we can get the instantaneous SNR at $\mathrm{UE_q}$ as

$$\rho_{UE,q} = \frac{P_{BS} P_{RN} |H_A|^2 |H_{B,q}|^2}{\left[P_{BS} |H_A|^2 + 2P_{RN} |H_{B,q}|^2 + N_O\right] N_O} \quad (14)$$

The achievable bit rates of the multi-hop node at each q^{th}-user is represented as [15]

$$R_{UE,q} = \frac{1}{2}\log_2(1+\rho_{UE,q}) \quad (15)$$

The following equations can be derived by applying (12):

$$\rho_{UE,q} = \frac{P_{BS} P_{RN} |H_A|^2 L(d_{B,q})^{-\alpha}}{\left[P_{BS} |H_A|^2 + 2P_{RN} L(d_{B,q})^{-\alpha} + N_O\right] N_O} \quad (16)$$

$$\rho_{UE,q} = \frac{P_{BS} P_{RN} |H_A|^2 L(v_{UE} T_{UE})^{-\alpha}}{\left[P_{BS} |H_A|^2 + 2P_{RN} L(v_{UE} T_{UE})^{-\alpha} + N_O\right] N_O} \quad (17)$$

where $d_{B,q}$ is the distance between RN and UE, v_{UE} is the velocity of $\mathrm{UE_q}$ toward RN at a travelling time of T_{UE}. This equation explains the SNR impact with variation the UE velocity.

2.2. Multi-user with Multi-Relay node

- Fixed $\boldsymbol{K}^{th}$-relay and $\boldsymbol{Q}^{th}$-user scheme

In the case, we proposed the new model for two-way AF-RNs, where the $\boldsymbol{K}^{th}$-relay nodes $\boldsymbol{K}=\{RN_1, RN_2, \cdots RN_k\}$ with $\boldsymbol{Q}^{th}$ users $\boldsymbol{Q}=\{UE_1,\ UE_2,\ \cdots UE_q\}$ in a distension side. All system analyses of the fixed and moving scenarios are introduced and shown in Figure 4. In this case, the interference between the RNs is ignored. Furthermore, we explain this performance mathematically.

We can represent the channel matrix for the access link as

$$H_{Bk,q} = \begin{bmatrix} H_{B1,1} & H_{B1,2} & \cdots & H_{B1,q} \\ H_{B2,1} & H_{B2,2} & \cdots & H_{B2,q} \\ \vdots & \vdots & \vdots & \vdots \\ H_{Bk,1} & H_{Bk,2} & \cdots & H_{Bk,q} \end{bmatrix}$$

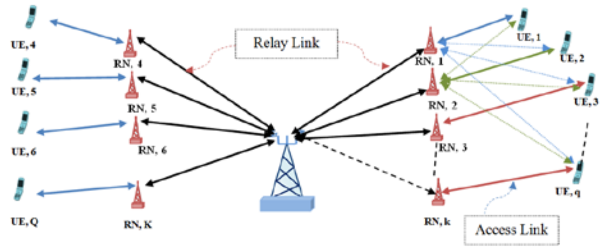

Figure 4. Multi scenario scheme model

The relay link between one base station and the $\boldsymbol{K}^{th}$ relay can be expressed as

$$H_{A,k} = \left[H_{A,1} \quad H_{A,2} \qquad \cdots H_{A,k}\right]$$

The gain factor for the $\boldsymbol{K}^{th}$ relay relative to the destinations can be expressed as

The gain matrix at the access link between the $\boldsymbol{K}^{th}$-MRN and $\boldsymbol{Q}^{th}$-UE can be expressed as

$$\eta_{k,q} = \begin{bmatrix} \eta_{1,1} & \eta_{1,2} & \cdots \eta_{1,q} \\ \eta_{2,1} & \eta_{2,2} & \cdots \eta_{2,q} \\ \vdots & \vdots & \vdots \\ \eta_{k,1} & \eta_{k,2} & \cdots \eta_{k,q} \end{bmatrix}$$

The second way signals received at the base station and the UEs from $\boldsymbol{K}^{th}$ relays are expressed as

$$\hat{y}_{BS}[t_2] = \sum_{k=1}^{K}\sum_{q=1}^{Q} \eta_k H_{Ak} H_{Bk,q} X_q[t_1] + \eta_k H_{Ak} n_{RN} + n_{BS} \quad (18)$$

$$\hat{y}_{UE,q}[t_2] = H_{Ak} \sum_{k=1}^{K} \eta_k H_{Bk,q} X_q[t_1] + \eta_k H_{Bk,q} n_{RN} + n_{UE} \quad (19)$$

The instantaneous SNR for the $\boldsymbol{q}^{th}$-user from the above equations is

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$$\rho_{UE,q} = \frac{\sum_{k}^{K} \eta_{k,q}{}^{2} P_{BS} \,|\, H_{Ak} \,|^{2} |\, H_{Bk,q} \,|^{2}}{\left(\sum_{k}^{K} \eta_{k,q}{}^{2} \,|\, H_{Bk,q} \,|^{2} + 1 \right) N_{O}} \quad (20)$$

After substituting (4) in (20) and performing the analysis, as well as retaining the same assumption in the previous section, we can get the instantaneous SNR at UE_q as

$$\rho_{UE,q} = \frac{P_{BS} P_{RN} \sum_{k}^{K} |\, H_{Ak} \,|^{2} |\, H_{Bk,q} \,|^{2}}{\left(\sum_{k}^{K} P_{BS} \,|\, H_{Ak} \,|^{2} + 2P_{RN} \,|\, H_{Bk,q} \,|^{2} + N_{O} \right) N_{O}} \quad (21)$$

The achievable rates of the q^{th}-users in this case can be represented as

$$R_{UE,q} = \frac{1}{2} \log_2 (1 + \rho_{UE,q}) \quad (22)$$

- Sharing velocities between nodes

In this section, a mobility model with AF-MRN and a two-way method are proposed where all UEs and RNs moved toward them at different velocities. The performance and impact of each node velocity on the SNR and bite rate within a two-way relay were analyzed.

Using (21) and (16), the instantaneous SNR in this case can be derived as

$$\hat{\rho}_{UE,q} = \frac{P_{BS} P_{RN} \sum_{k=1}^{K} |\, H_{Ak} \,|^{2} \; L(v_{RN} T_{RN})^{-\alpha}}{\left[P_{BS} \sum_{k=1}^{K} L_{1} (v_{RN} T_{RN})^{-\alpha} + 2P_{RN} \,|\, H_{Ak} \,|^{2} + N_{O} \right] N_{O}} \quad (23)$$

where the v_{RN} is the velocity of RN_k toward UE_q at a travelling time of T_{RN}, whereas L_1 is the gain parameter between the source and destination.

We shared the travelling time between the relays and users to combine the hybrid node velocities between the K^{th} relay and Q^{th} users as shown in Figure.5

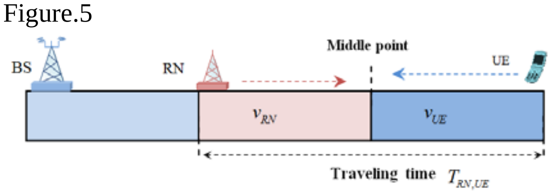

Figure 5. Travelling time sharing

$$\hat{\rho}_{UE,q} = \frac{P_{BS} P_{RN} \sum_{k=0}^{K} |\, H_{Ak} \,|^{2} \, L_{1} (v_{RN} T_{RN})^{-\alpha}}{\left[P_{BS} \sum_{k=1}^{K} L_{1} (\underbrace{v_{RN} \frac{T_{RN}}{2}}_{\text{Relay velocity}} + \underbrace{v_{UE} \frac{T_{UE}}{2}}_{\text{User's velocity}})^{-\alpha} + 2P_{RN} \,|\, H_{Ak} \,|^{2} + N_{O} \right] N_{O}} \quad (24)$$

$$R_{UE,q} = 0.5 \log_2 (1 + \hat{\rho}_{UE,q}) \quad (26)$$

3. POWER-BALANCING ALGORITHM

Moving relays are generally mounted on a vehicle, such as the bus and train [16] shown in Figure 6.

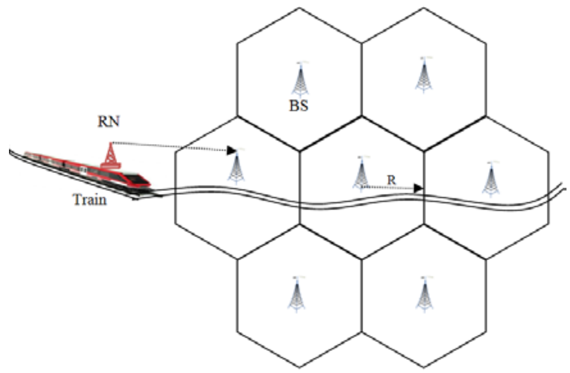

Figure 6. The applications of Moving Relay scenario scheme

MRS has better transmitted power and antennas diversity gain than users, thus the relay link will be better than the direct link between BS and UE, so one of the main contributions of MRS is that it can effectively enhance the system capacity and throughput.

Logically the coverage area and SNR are not equally distributed over cell radius, the capacity near of sender is better than of cell boundary Thus, the users at the cell boundary can cause blocking since SNR is very low at cell edge.

The SNR at equations 11, 14 depend on the transmitted power and path loss between transmitter and receiver, so, we proposed new algorithm to balance transmitted relay power.

The proposed algorithm is to control on the transmitted power of MRN over cell radius to achieve the required SNR and throughput at the users with mitigate the consumption transmitted relay power, then no need to consume additional power if we get a good SNR near the station. This algorithm is explained in Figure7.

We assumed two constrain in the proposed algorithm:

minimize P_{RN}

subject $0 < P_{RN} \le P_{RN,\max}$

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$$\rho_{th} < \rho_{RL} \le \rho_{\max}$$
$$\rho_{DL} < \rho_{th}$$

where the ρ_{RL}, ρ_{DL} is SNR at relay link, and direct link respectively, ρ_{th}, $\rho_{\max}$ is the threshold and maximum required SNR at the UE.

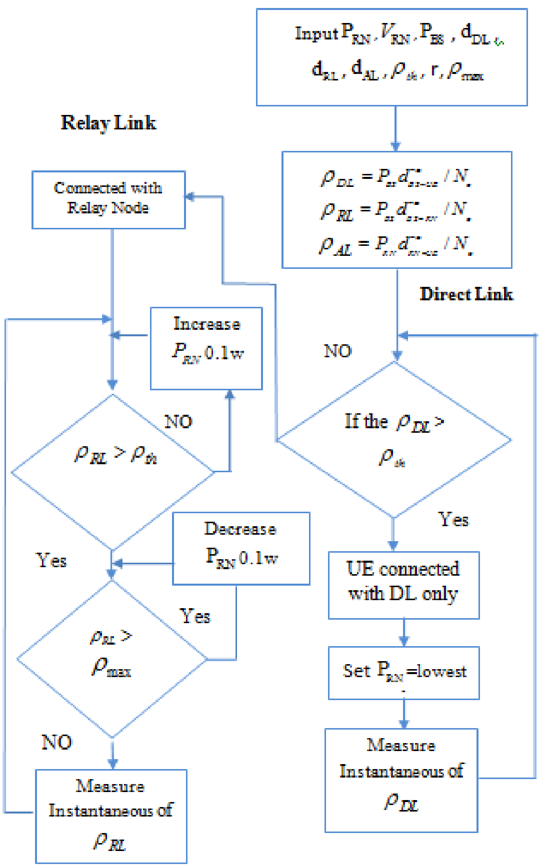

Figure 7. The flowchart of power balanced algorithm

4. RESULTS AND DISCUSSION

In this section, we present the numerical results of the two scenarios with the two mobility case problems formulated in Sections 2 and 3. The system parameters were chosen based on Table (1) [17]. Figure 8. shows the bit rate at the downlink versus the SNR at the direct and multi-hop links. The multi-hop link enhanced and increased the bit rate and SNR at the downlink.

In the second case, the mutations of the UE velocity rather than that of the bit rate are observed. When the UE moved toward the RN, the bit rate increased when it approached the UE from the RN coverage. We plot this relation with the different latencies, as illustrated in Figure 9.

Figure 10. shows the bit rate versus the SNR for a number of relays at the downlink, where an increased number of relays in the cell produces a high bit rate and a high SNR. This figure explains the four cases of using multi-hop relay and one case without using a relay node.

For the mobility scenario, where an AF-MRN with a two-way method is used, the UEs and RNs moved toward them.

Table1: Simulation Parameters

Carrier frequency	2G
Band width	5M
Number of BS	1
Antenna height of the BS	25(m)
BS antenna gain	17 dBi
Max. Tx. power of BS	46dBm
BS noise Figure	5 dB
Number of RNs	1-6
Antenna height of the RN	3m(above train or bus)
RN Tx. power	30 dBm,1W
RN-UE antenna gain	5dBi
RN-BS antenna gain	7dBi
Noise figure of RN	5 dB
Antenna height of the UE	1.5m
Antenna gain of UE	0dBm
Noise figure of UE	6 dB
ρ_{th}	30dB
$\rho_{\max}$	45dB
$P_{RN,\max}$	40dBm,10w

Figure .11 illustrates the time-sharing between the RN and UE. When the RN moved toward the UE from the BS, and the relay link is in decay, the bit rate is thus reduced at the RN. On the other hand, the bit rate is increased at the UE when the UE is away from RN and close to BS.

The coverage area distribution over real map with terrains is illustrated in Figure 12a. by using ATDI Radio planning software with 20m map resolution, where is clear that the coverage area at the centre is better than cell boundary ,also the improvement in the coverage area by deployment six FRN at 1600 m from BS , near the cell edge as shown in Figure 12b. These figures are proposed with 30 dB of ρ_{th}.

The results in figure 13 explain the transmitted power saving for MRN when travels straight toward the BS, where there is saving power nearly 60% without deploy FRN and nearly 75%

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after deployment 6 relay each one with 5 watt at distance 1600m from BS.

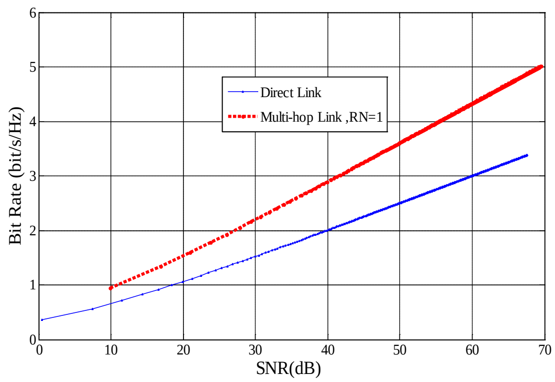

Figure 8. Bit rate and SNR enhancements between the direct and relay links

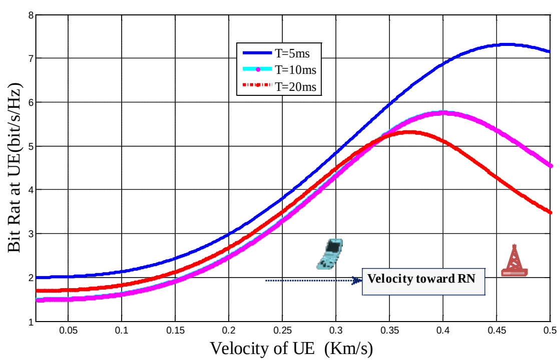

Figure 9. Movement of UE toward RN at different latency times

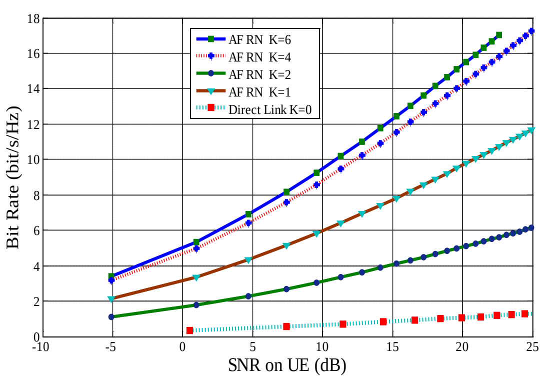

Figure (10) Bit rate and SNR enhancements using different relay nodes

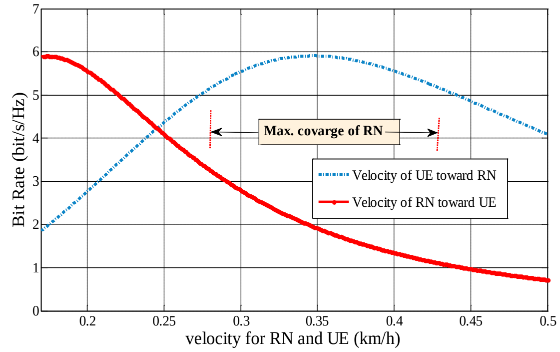

Figure 11 Bit rate change with the change in movement for both the UE and RN

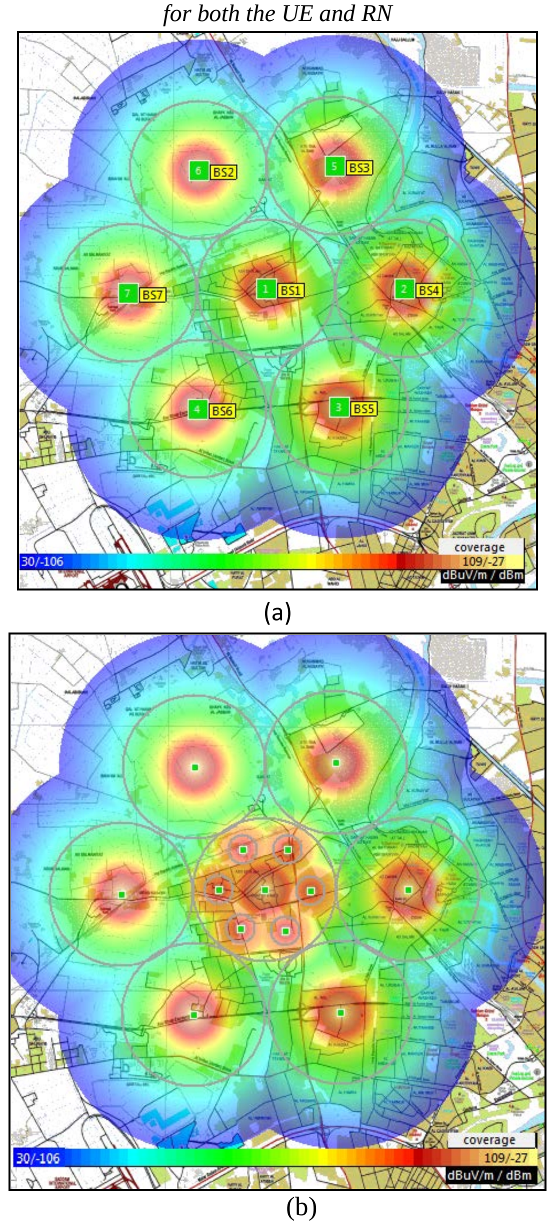

Figure 12. Chromatic scheme of LTE-A coverage area over real map terrains(a) No FRN (b) with 6FRN 5W at 1600 m from BS

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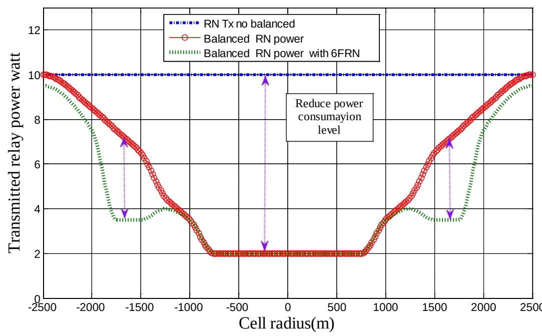

Figure 13. Saving transmitted power of MRN over cell radius

5. CONCLUSION

In this paper, we analyzed two scenarios for FRNs and MRNs with a half-duplex mode in a cell. We studied the performance of multi-user AF RNs with uplink and downlink styles, considering the path loss between the source and destination. Two scenarios were considered in studying the enhanced coverage area and bit rate using RNs to support the base stations. Moreover, we proposed a control power algorithm for MRN, this algorithm is balance of the transmitted power over cell radius to achieve the required SNR and throughput at the users with mitigate the consumption transmitted relay power. The simulation results are conducted to consumption transmitted relay power by using ATDI simulator, which deals a real digital cartographic representation of an urban area. The results indicated there is saving nearly 75% from transmitted power by relay after using proposed algorithm.

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