http://dx.doi.org/10.5755/j01.eee.20.7.3379 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 20, NO. 7, 2014

Optimizing Power and Mitigating Interference in LTE-A Cellular Networks through Optimum Relay Location

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***Abstract*—In this paper, we propose new scheme for an optimum location for Relay Node (RN) in LTE-A cellular network to enhance the capacity at cell edge based on modified Shannon capacity for LTE networks. The proposed approach mitigates interferences between the nodes and ensures optimum utilization of transmitted power. In addition, this papers the mathematical derivation of optimal number of RNs per cell to prevent the overlapping between neighbouring RNs meanwhile providing the best coverage. Mathematical results are validated by Simulation results and indicate an improvement in capacity for users at the cell edge from 0.6 b/s/Hz to 1.45 b/s/Hz and 40% increment from all cell capacity. Moreover, a gain about 8 dBm and 25 dBm is observed for users at the cell edge for uplink and downlink in the received signal respectively. It has been concluded from the numerical analysis which is conducted on limited interferences for all nodes (in-band and out-band) provides simplicity and ease in implementation by the RF planning designers.**

***Index Terms*—LTE-A, relay node, received signal, spectral efficiency.**

I. INTRODUCTION

One of the solutions to meet growing demand and stringent design requirements for coverage extension and throughput and capacity enhancement is to increase the number of base stations (BSs), with each station covering a small area. However, increasing the number of BSs requires high deployment cost [1]. Deploying RNs has been considered a promising solution to enhance the capacity and coverage area with low cost. However the enhancements in capacity and coverage are based on location for RN in the cell to mitigate the interference and between BSs generated from deploying RNs [2], [3]. RN is part of the cellular network infrastructure; therefore, their deployment will be an integral part of the network planning, design, and deployment process. One of the open questions regarding the deployment of wireless networks using RN is the optimal location for RNs that can provide maximum capacity and the number of relay stations per cell compared with the total cost. Based on the spectrum used for access and relay links, relaying can be classified into out-band and in-band types [2], [4]. Out-band relaying implies that relay link operators are used in a spectrum which is different from that of access link operators. In-band relaying implies that relay and access links operate in the same spectrum, however, that require additional mechanisms to avoid interference between the access and relay links. Non-transparent relay carries control signalling along the same path as that of data traffic. In transparent relay mode, a UE linked to an RN is located within the coverage of the BS, where the control signalling from the BS can directly reach the UEs, while data traffic is relayed via relay node. In this relay mode, control signalling and data traffic are separated. In this paper, we focus on transparent relay that focuses on throughput improvement, in which the UE is located within the coverage of BS DL control channel.

In this work a new model that entails the deployment of RN in LTE-A cell with interference limited between the nodes. One of contributions in this work is that based on modified Shannon formula according Modulation and Coding Scheme (MCS) to provide realistic transmission in comparison conventional Shannon formula [3]. This paper presents the derivation of saturation capacity which lies near higher resource links such as BS and RN, which is determined from 200 m to 500 m [3]. Moreover, the mathematical results are verified using the ATDI simulator, which deals with a real digital cartographic and contains standard formats for terrain, images, and vector data.

II. SYSTEM MODEL

The received signal at the downlink for each user k in conventional cellular (i.e. cellular without RNs) is represented as the following equation [5]

$$Y_{i,k} = \sqrt{P_i} B_{i,k} X_{i,k} + \sum_{j=0}^{N_{cell}} \sqrt{P_j} B_{j,k} X_{j,k} + N_k, \qquad (1)$$

where $j = 0 \rightarrow N_{cell}$, N_{cell} is the number of neighbouring cell; P_i and P_j are the transmit power of donor BS and neighbouring *BSs*, respectively; $B_{i,k}$ and $B_{j,k}$ are the fading channel gain for donor and neighbouring cell, respectively. SINR ($\rho_{i,k}$) from i^{th} link (*BS*$_i$) in each single sub-carrier (k) UEs with ignored background noise N_k to simplify the calculations, can be written as [5]–[7]

Manuscript received January 25, 2013; accepted March 10, 2014.

$$\rho_{i,k} = \frac{P_i L D_{i,k}^{-\alpha}}{\sum_{j=1}^{N} P_j L_j d_{j,k}^{-\alpha}}, \tag{2}$$

where the B is the function of path loss, $|B|^2 = LD^{-\alpha}$, $L = G_r G_t$ is constant depending on the infrastructure of sender and receiver, $G_r G_t$ is the antenna gains of the transmitter, and receiver respectively, $D_{i,k}$ and $d_{j,k}$ are the distances from user to donor BS_i and neighbour BS_j respectively, α is the path loss exponent [8], [9].

A. *Capacity of Cell without Relay*

Based on [10], [11], the capacity in a single-input single-output LTE system can be estimated by

$$C_i = \min\left\{BW_{eff} \log 2(1+\rho_i / \rho_{eff}\ ),\ C_{\max}\right\}, \tag{3}$$

where C_i is the estimated spectral efficiency in bps/Hz, $C_{\max}$ is the upper limit based on the hard spectral efficiency given by 64QAM with the coding rate of 0.753 equal to 4.32 bps/Hz [1], [4], [7]. ρ_i is the SINR for each user in the cell, BW_{eff} is the adjustment for the system bandwidth efficiency, and ρ_{eff} is the adjustment for the SINR implementation efficiency.

(BW_{eff}, ρ_{eff}) has the value of (0.56, 2.0) in the downlink and {0.52, 2.34} in the uplink [10]. Based on modified Shannon formula the cell capacity divides to two regions; the first lies around the BS is known as the estimated saturation capacity which is specified from $0 \to X_S$, while the other region is determined from X_s *to* R ,where in this region, the cell capacity is never constant as shown in Fig. 1.

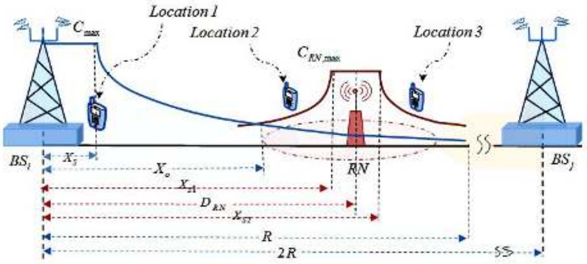


Fig. 1. Proposed model of optimum location for RN and inference on UE.

To calculate the saturation distance x_s, where the level capacity is equal to $C_{\max}$ at location (1), as shown in Fig. 1, the received signal at UE can be written as

$$Y_{i,x_s} = \sqrt{P_i} B_{i,x_s} X_{i,x_s} + \sum_{j=0}^{N_{cell}} \sqrt{P_j} B_{j,x_s} X_{j,x_s} + N_{x_s}. \tag{4}$$

The ideal SINR at X_s location is

$$\rho_{ideal} = \frac{P_i L X_s^{-\alpha}}{P_j L_1 (2R - X_s)^{-\alpha}}, \tag{5}$$

where L_1 is constant depending on the infrastructure of neighbour BSs.The Error Vector Magnitude (EVM) is a measure of the difference between the ideal symbols and the measured symbols after the equalization[12]. This difference is called the error vector magnitude. For 64QAM modulation in LTE system the SINR (ρ_{i,X_s}) at X_s location is explained as [12], [13]:

$$\frac{1}{\rho_{i,X_s}} = \frac{1}{1/\rho_{max} + 1/\rho_{ideal}}, \tag{6}$$

$$X_s = \frac{2R}{1 + \left(P_i L / P_j L_1\right)^{\frac{-1}{\alpha}} \left(\rho_{i,X_s}\right)^{\frac{1}{\alpha}} - \left(\rho_{max}\right)^{\frac{1}{\alpha}}}. \tag{7}$$

For downlink LTE network the $\rho_{max} = 0.08$ with 64QAM [12], [14]. The distance X_s depends on the infrastructure of the sender and the effect of interference from other cells.

The capacity near the sender is better than that near the cell boundary therefore the users at the cell boundary can cause blocking, and outage probability is high because the number of accepted users is directly proportional to the resources of the service provider. RN fits perfectly to improve the SINR at the cell boundary, thereby increasing capacity, can possibly increase the number of accepted users. However, the RN and BS are located at a certain distance from each other, in which the SINR at UE from the relay link is equal to the SINR for direct link, where the user is in a handover case [15]. The received signal at UE from BS via direct link is equal to the signal from RN via relay link at certain location [9]. This location is known as the handover point, as shown in Fig. 3. Therefore the distance from the BS to the said location is X_O, as shown in Fig. 2. The distance from relay location (D_{RN}) to X_O is $D_{RN} - X_o$. Thus, the SINR via BS (ρ_{i,X_o}) and via RN (ρ_{RN,X_o}) are:

$$\rho_{i,X_o} = \frac{P_{BS} L X_o^{-\alpha}}{P_{RN} L\ (D_{RN} - X_o)^{-\alpha}}, \tag{8}$$

$$\rho_{RN,X_o} = \frac{P_{RN} L (D_{RN} - X_o)^{-\alpha}}{P_i L X_o^{-\alpha}}. \tag{9}$$

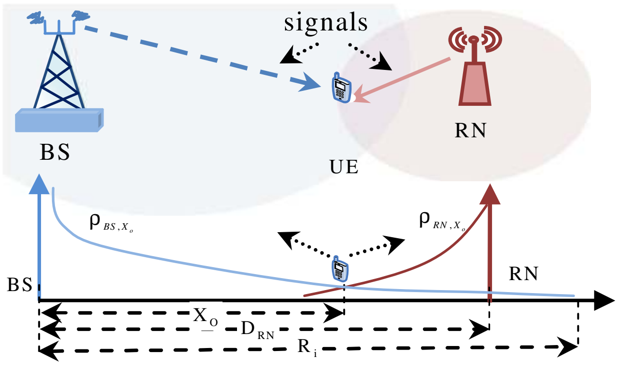


Fig. 2. Handover process performance.

Evaluating the X_o according to (8), (9) is

$$\frac{P_i L X_o^{-\alpha}}{P_{RN} L_r (D_{RN} - X_o)^{-\alpha}} = \frac{P_{RN} L_r (D_{RN} - X_o)^{-\alpha}}{P_i L X_o^{-\alpha}},$$

$$X_o = \frac{D_{RN}}{\left(\left(\frac{L_r P_{RN}}{L P_i} \right)^{\frac{1}{\alpha}} + 1 \right)}. \quad (10)$$

B. Capacity of Relay Node

The equations of relay coverage are calculated based on limitations exist between the locations 2 and 3 (as indicated in Fig. 1). The SINR for these two locations are:

$$\rho_{RN,2} = \frac{P_{RN} L_r (D_{RN} - D_i)^{-\alpha}}{P_i L D_i^{-\alpha}}, \quad (11)$$

$$\rho_{RN,3} = \frac{P_{RN} L_r (D_i - D_{RN})^{-\alpha}}{P_i L D_i^{-\alpha}}, \quad (12)$$

$$C_{RN,2} = \min\left\{ BW_{eff} \log_2\left(1 + \frac{P_{RN} L_r (D_i - D_{RN})^{-\alpha}}{P_i L \rho_{eff} D_i^{-\alpha}} \right), C_{R\max} \right\}, \quad (13)$$

where $X_o < D_i < X_{s1}$.

$$C_{RN,3} = \min\left\{ BW_{eff} \log_2\left(1 + \frac{P_{RN} L_r (D_{RN} - D_i)^{-\alpha}}{P_i L \rho_{eff} D_i^{-\alpha}} \right), C_{R\max} \right\}, \quad (14)$$

where $X_{s2} < D_i < R$ otherwise equal $C_{R\max}$.

$C_{R\max}$ is the maximum spectral efficiency of relay that depends on the adaptive MCS of modified Shannon formula.

III. Optimum Relay Location

In this section, the issue of the optimum placement of the relay node deployment in a dual-hop network over LTE-A cellular networks will be addressed as well as the maximum throughput and limited interference between all in-band and out-band stations. The optimum location for RN at the cell edge identified by two locations is $(D_i = X_o)$ and $(D_i = r)$. By using this domain in (13) and (14) can be calculate the optimum location for RN through the following:

$$BW_{eff} \log_2\left(1 + \frac{P_{RN} L_r (D_{RN} - X_o)^{-\alpha}}{P_i \rho_{eff} L X_o^{-\alpha}} \right) =$$

$$= BW_{eff} \log_2\left(1 + \frac{P_{RN} L_r (R - D_{RN})^{-\alpha}}{P_i \rho_{eff} L R^{-\alpha}} \right), \quad (15)$$

$$X_o (R - D_{RN}) = R (D_{RN} - X_o). \quad (16)$$

Substituting (10) in (16), we obtain the optimum location of RN

$$D_{RN} = R \left(1 - \left(\frac{L_r P_{RN}}{L P_i} \right)^{1/\alpha} \right), \quad (17)$$

From (17) the relay location depends on the cell radius, the properties of the relay node and the base station, and the path loss exponent. This equation limits the relay location between X_o and R.

IV. Optimum Number of Relays in Cell

To enhance the coverage area, the optimum number of relays should be calculated to avoid the overlapping between deployed RN and reduce the overall cost.

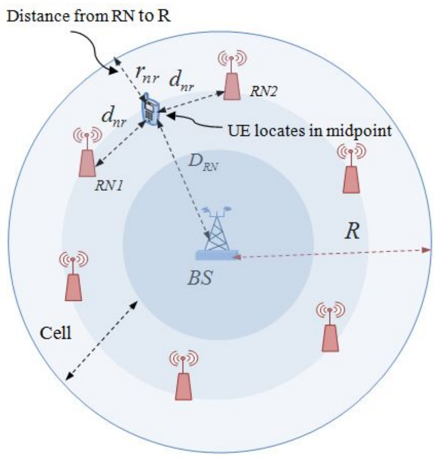


Fig. 3. Constraint of relay deployment at one cell.

The deriving optimum number of relays (N_{relays}) based on assuming that a UE is present in the midpoint between two RNs, and that d_{nr} is the distance from each RNs, as illustrated in Fig. 3. Logically increasing the number of RNs can improve cell capacity on the condition that the interference between RNs does not exceed the interference from the BS [16]. The path loss between the two points:

$$P_{RN1} L (d_{nr})^{-\alpha} + P_{RN2} L (d_{nr})^{-\alpha} > P_i L (D_{RN})^{-\alpha}, \quad (17)$$

$$2 d_{nr} = \frac{2\pi D_{RN}}{N_{relays}}, \quad (18)$$

$$\frac{2 L P_{RN}}{L P_{BS}} \left(\frac{\pi D_{RN}}{N_{relays}} \right)^{-\alpha} > (D_{RN})^{-\alpha}, \quad (19)$$

$$N_{relays} < \pi \left(\frac{2 L P_{RN}}{L P_i} \right)^{\frac{-1}{\alpha}}. \quad (20)$$

From (20), the number of relays depends on the properties of both RN and BS as well as on the path loss exponent α.

V. Simulation Calculation

The signal strength in the service area must be measured to design a more accurate coverage of modern LTE networks. The propagation of a radio wave is a complicated and less predictable process if the transmitter and receiver properties are considered in channel environment calculations. The process is governed by reflection, diffraction, and scattering, the intensities of which vary under different environments at different instances.

The ATDI simulator is used to approve the mathematical model for optimum relay placement. The propagation model for this simulator between the nodes can be expressed as the following

$$P_r = P_t + G_t + G_r - L_{prop} - L_t - L_{re}, \text{[dB]}, \quad (21)$$

where P_t indicates the power at the transmitter and P_r is the power at the receiver; G_t and G_r are the transmitter and receiver antenna gains, respectively; L_t and L_{re} express the feeder losses; and L_{prop} is the total propagation loss [9].

This equation describes the link budget. A link budget describes the extent to which the transmitted signal weakens in the link before it is received by the receiver. The link budget depends on all the gains and losses in the path, which is facing the transmitted signal to reach the receiver. A link is created by three related communication entities: transmitter, receiver, and a channel (medium) between them. The medium introduces losses caused by suction in the received power

The SINR at the UE over the simulation test can be explained by using the following

$$SINR_{sim} = \frac{P_r}{N_o + \sum_{j=1}^{j=N} P_{rj}}, \quad (22)$$

where the $SINR_{sim}$ is the received SINR by the user and calculated by the simulator; P_{rj} is the received signal from the neighbouring cell; and $j = \{1 \cdots N\}$, where N is the number of neighbouring cells. For simplicity, we suggested the use of the first tier (six cells around the centralized cell) in planning for an urban area, with N_o as the background noise at the receiver

$$SINR_{sim} = \frac{P_t G_t G_r / L_{prop} \; L_t \; L_{re}}{N_o + \sum_{j=1}^{j=N} P_j G_{t,j} G_r / L_{prop,j} \; L_j \; L_{re}}, \quad (23)$$

where L_t, L_j, L_{re} are the feeder loss for senders (central BS and the surrounding BS_j) and destination

$$C_{sim} = 0.5 \log_2 \left(1 + SINR_{sim}\right), \quad (24)$$

VI. SIMULATION RESULTS

In this section, the mathematical results for the proposed model are explained and compared with simulation results using the ATDI simulator, which uses a real digital cartographic representation of an urban area.

The numerical and simulation curves are the results of the proposed mathematical model for three optimum locations (1250, 1660, and 1950 m from the BS) based on (17), (18) and summarized in Table I. This model aims to improve the capacity and signal strength at the cell edge while mitigating interference between all stations.

Figure 4 shows the spectral efficiency versus cell radius according to (3) and the simulation which considered the interferences for first tier (six cells around the main cell) and considered the frequency reuse.

TABLE I.DATA BASE OF THREE SCENARIOS

Case	N_{relays}	P_{BS} (watts)	P_{RN} (watts)	D_{RN} (m)
Case1	4	40	10	1250
Case2	6	40	5	1600
Case3	9	40	2	1920

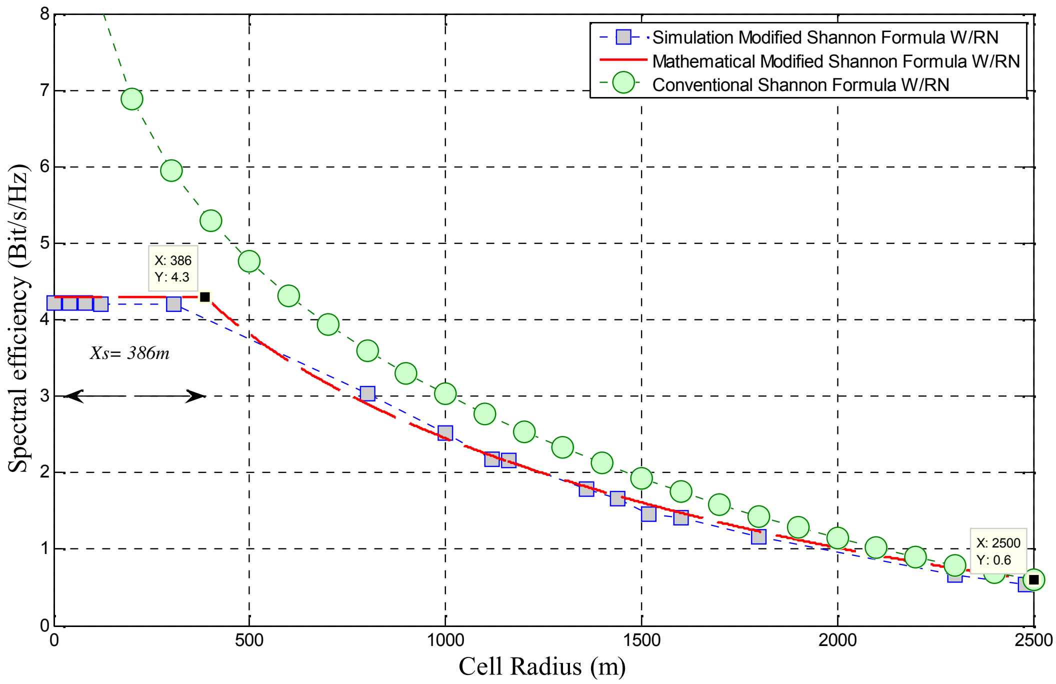


Fig. 4. Mathematical and simulation results of spectral efficiency versus the cell radius of conventional cell (without RNs).

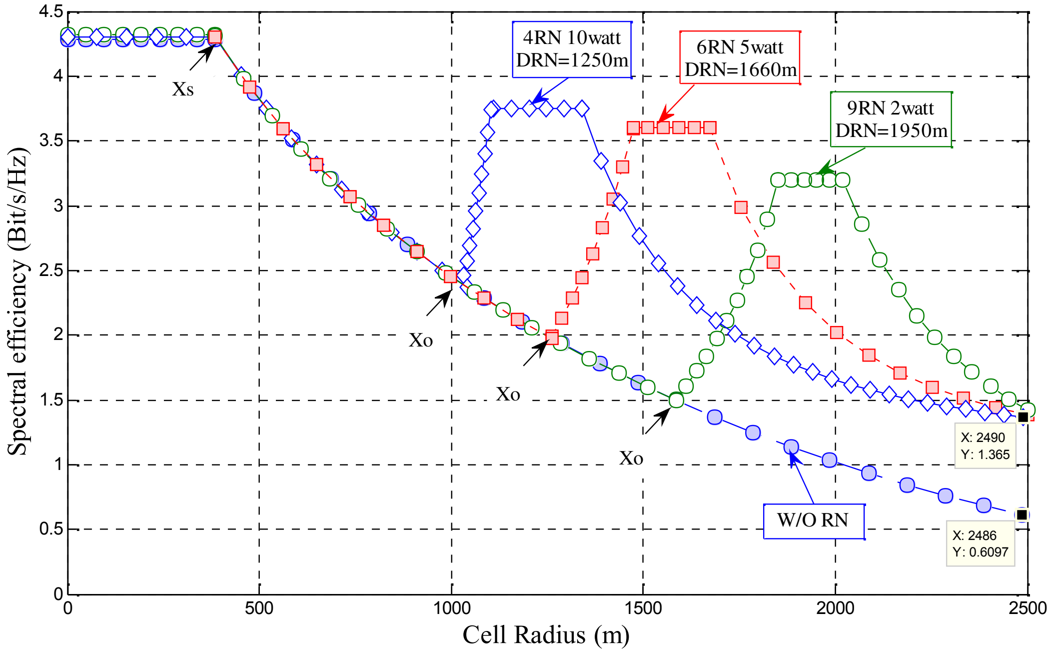


Fig. 5. Spectral efficiency of three proposed schemes over cell radius.

According to the proposed model the spectral efficiency at cell edge is improved from 0.6 bps/Hz to 1.45 bps/Hz for each suggested location as shown in Fig. 5. The allocated RN transmitted power is considered for each chosen location that illustrates in database of the dependent parameters in Table I.

A proposed scheme provides the same SINR at the cell edge at choosing any one of relay locations or the transmitted power of relay. Thus, the interference will be limited at the boundaries of cells so that we got the same improvement for each proposed location. The mathematical results for three proposed locations are shown in Fig. 5.

The simulation results are verified as shown in Fig. 6(a)–Fig. 6(d) based on a real digital cartographic representation of an urban area that is approximately 176.7 km^2.

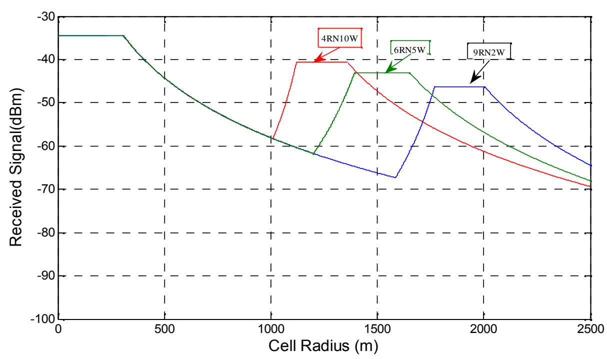
These results for three scenarios are illustrated in Fig. 6(a) demonstrates the relationship of the received signal strength (RSS) at user with cell radius. The enhancement of the RSS for proposed model is 25 dBm at the boundaries and 40 % for cell edge region. This enhancement in RSS is almost equal for each proposed location. The simulated parameters in Table II are chosen according to [18].

The total covered areas (density or radiation power) for three proposed scenarios (Case1, Case2, and Case3) in Table I are approximately similar in magnitude as mentioned in Fig. 6(a)–Fig. 6(d).

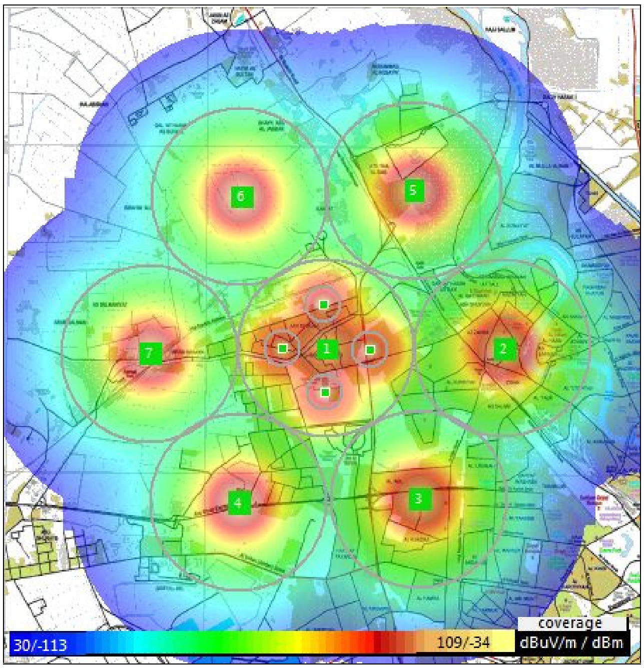
To obtain the optimal relay placement we must take in account the downlink (DL) and uplink (UP)performance, where the DL and UL transmission are asymmetrical in terms of maximum transmit power and coverage. Figure 7 explains the downlink and uplink of the received signal strength of users versus cell radius with two ways DL and by considering case 2 in Table I (6RN5W) .This location improved the uplink signal strength 8 dBm. This improvement is decreased the outage connection probability for user that far away from BS.

TABLE II. SIMULATION PARAMETERS.

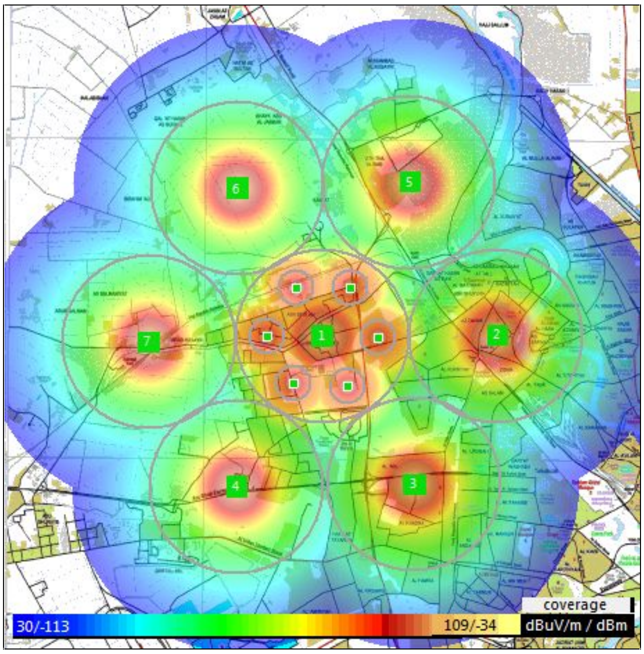
Carrier Frequency GHz	2
Bandwidth	1.4 MHz
Number of BS	7
Antenna height of BS	25 (m)
Antenna gain	17 dBi
Type of antenna	Omi directional
Transmitted power of BS	40 W
Number of recourse block (RBs)	6
Modulation and coding schemes	64QAM code (0.625,0.6) 16QAM code 0.8 [10]
Radius of cell	2500 m
Antenna height of RN	25 (m)
Antenna gain of RN	5 dBi
Transmitted power of RN	10,5,2 [W]
Number of UE	1
Antenna height of UE	1.5 m
Antenna gain	0 dBm
Coverage threshold	-30 dBm



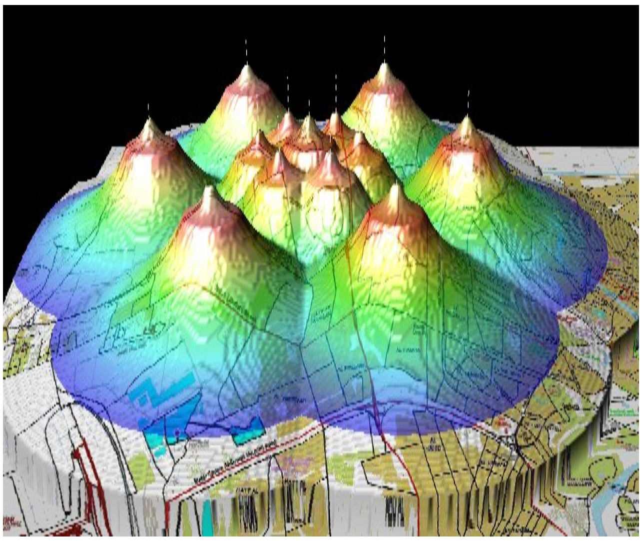
(a)



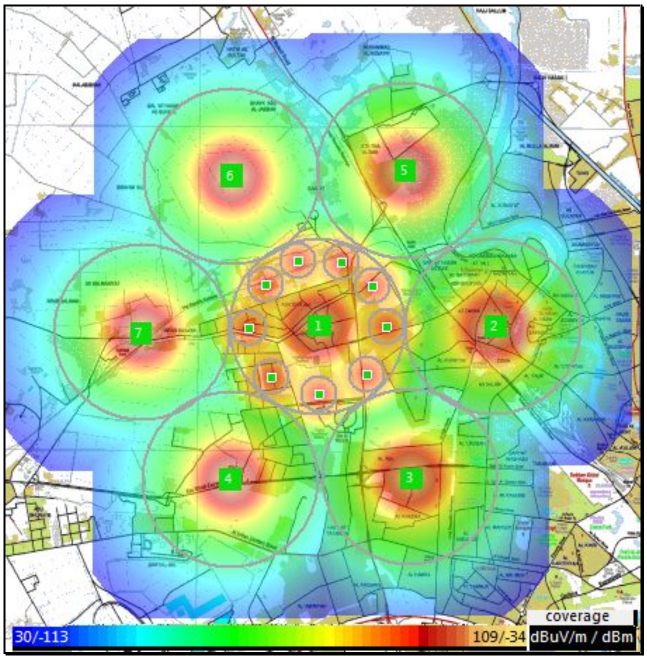
(b)



(c)



(d)



(e)

Fig. 6. Received signal strength versus the distance with a real digital cartographic of an urban city, (a) mathematical representation of received signal strength at UE for a three proposed relay locations respectively, (b) chromatic scheme of coverage area distribution for 4RN 10W, (c, d) 2dimansion and 3dimansion chromatic scheme of coverage area distribution for 6RN 5 W respectively (e) chromatic scheme of coverage area distribution for 9RN 2 W.

VII. CONCLUSIONS

This paper presented a new approach for optimal location for RN. The approach maximized the capacity and signal strength at users with two-way performance at the cell edge, whereas it mitigated interference between all nodes. It has been proved from the derivation that the proposed model provided the best coverage and power allocation with no need for additional BSs. It has been concluded that the proposed approach is a solution to frequent interruptions due to low SINR at the cell edge in LTE cellular networks. This work presented the balance in the resource sharing between BS and RNs that can yield insight into future research directions. Theoretical analysis is conducted to limit interferences and to ensure simplicity and ease in implementation by RF planning designers. In this work the ATDI simulator verified the numerical results and showed improved capacity and signal strength for users at the cell edge region.

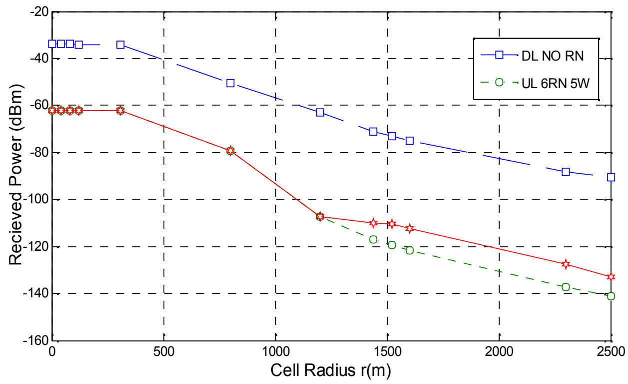


Fig. 7. Unlink and Downlink of RSS in multi hop performance against cell radius.

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