Optimal Relay Placement for Coverage Extension in LTE-A Cellular Systems

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***Abstract*—Third Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-A) has considered the deployment of Relay Nodes (RNs) for cost-effective throughput enhancement and coverage extension. The coverage extension (increase in cell radius) depends on the radial position of RNs in the cell. This is because the location of a RN affects the Signal-to-Interference-plus-Noise Ratio (SINR) of the received signal on the evolved-NodeB (eNB)-RN and RN-User Equipment (UE) links. In this paper, we investigate the problem of optimal relay placement for coverage extension in relay assisted LTE-A networks. Since DownLink (DL) and UpLink (UL) transmission scenarios in cellular networks are asymmetrical in terms of coverage (due to discrepancy in maximum transmit power), we consider both DL and UL transmission scenarios for optimal relay placement. In addition, we analyze the problem for the case when interference from neighbouring cells is taken into account.**

I. Introduction

Long Term Evolution-Advanced (LTE-A) is a technological advancement proposed by the Third Generation Partnership Project (3GPP) to meet the requirements of Fourth Generation (4G) mobile broadband system. The underlying radio technology of LTE-A networks is based on Orthogonal Frequency Division Multiple Access (OFDMA) which has inherent immunity to the adverse consequences of frequency selective fading. Moreover, Multiple Input Multiple Output (MIMO) techniques and coordination among multiple cell sites called Coordinated MultiPoint (CoMP) transmission/reception are regarded as the key techniques to meet the requirements of 4G in LTE-A [1]. Yet, capacity at the cell edge remains relatively small due to low Signal-to-Interference-plus-Noise Ratio (SINR)) at the cell edge compared to inner regions of the cell [2]. Therefore, a cost effective solution of deploying Relay Nodes (RNs) is proposed in LTE-A.

Deploying RNs in a cellular network has two key benefits: cell capacity improvement and cell coverage extension. RNs can provide higher cell capacity in a given cell area beacuse of the link diversity. Link diversity is achieved because of the two possible links between User Equipment (UE) and Base station (termed as evolved-NodeB (eNB) in 3GPP-LTE): direct link (between UE to eNB) or the indirect link (between UE to eNB via RN). Alternately, RNs help increase the cell coverage (cell radius) for the same cell capacity. Increment in cell radius due to deployment of RNs reduces infrastructure cost of deploying more eNBs. The coverage extension due to RN deployment is achieved since RNs provide better SINR to the cell edge UEs compared to eNB due to their proximity to UEs. The increase in cell radius depends on the radial position of RNs in the cell. This is beacuse the location of a RN affects the SINR of the received signal on the eNB-RN (backhaul) and RN-UE (access) links. Deploying a RN away from cell edge causes low SINR on the access link (due to increase in path loss). This increases the outage probability (probability that the received signal strength is below acceptable thresholds) of cell edge UEs. On the other hand, deploying a RN near cell edge will result in higher interference to the neighboring cells. Therefore, an optimal location for relay placement needs to be determined for maximizing cellular coverage.

Limited contribution is available in the literature which addresses the problem of optimal RN placement to maximize coverage extension. In [3] and [4], the authors analyze the RN placement issue in IEEE 802.16j Worldwide Interoperability for Microwave Access (WiMAX) networks from the perspective of increasing system capacity. In [5], optimal RN placement issue is addressed from the perspective of cellular coverage extension. Authors define the cellular coverage in terms of probability of correct decoding and use an iterative algorithm to evaluate the optimal RN placement for Downlink (DL) transmission scenario. Since DL and UpLink (UL) transmission scenarios in cellular system are asymmetrical in terms of coverage (due to discrepancy in maximum transmit power), the optimal relay placement will be different for each of the scenarios considered individually. An optimal RN placement location evaluated with only DL into consideration can adversely affect the performance in UL scenario and vice-versa. Hence, a joint optimization problem needs to be formulated with both DL and UL scenario into consideration in order to determine the optimal RN placement in cellular systems.

In this paper, we extend the work in [5] to formulate a joint optimization problem. We analyze this problem within the framework of LTE-A standards [6]. However, it can be applied to any cellular system. We define coverage radius of the cell in terms of probability of correct decoding at a point, as defined in [5]. We determine the optimal location for RN placement to achieve maximum coverage radius for the scenarios with and without interference. We also analyze the variation in optimal

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location of RN placement for varying decoding thresholds and load conditions. The optimal relay placement location and the extended coverage radius evaluated in this paper can be practically used as a system design parameter since it is optimized with both UL and DL scenarios into consideration.

The rest of the paper is organized as follows. In Section II, we describe the system model. Section III gives the problem formulation, illustrates the optimal relay placement methodology for scenarios with and without interference. Section IV presents the results and inferences and finally, Section V concludes the paper.

II. System Model

We consider a two hop LTE-A cellular system. The system model comprises a reference cell surrounded by the first tier of co-channel cells. Each cell consists of N number of RNs placed symmetrically around eNB (at the distance R_b from eNB). The maximum transmit power of eNB, RN and UE are denoted by P_{eNB}, P_{RN} and P_{UE} and the antenna gains of eNB, RN and UE are denoted by G_{eNB}, G_{RN} and G_{UE} respectively. The maximum transmit power values are 46, 30 and 24 dBm and antenna gains are 16, 5 and -1 dB for eNB, RN and UE respectively as per the LTE-A specifications [6].

We consider log normal shadowing ξ on both the access and backhaul links, where ξ is a Gaussian random variable with mean 0 and standard deviation σ_a and σ_b for the access and backhaul link, respectively. We ignore the impact of fast fading as our objective is to evaluate the value of optimal RN placement from a long term prospect. Therefore, the evaluation carried out in this paper is applicable to both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) based LTE-A systems.

III. Optimal Relay Placement for Coverage Extension

We formulate the problem in Section III-A and begin our analysis in Section III-B for an interference-free scenario where the impact of Inter-Cell Interference (ICI) is neglected. Then, in Section III-C, we analyze the problem of optimal relay placement considering the impact of ICI from the first tier of co-channel cells.

A. Problem Formulation

The authors in [5] define coverage radius in terms of probability of correct decoding in DL (pc^d) at a point. For the DL scenario of a single hop network pc^d is given by:

$$\begin{aligned} pc^d &= Pr(SINR_{eNB-UE} > T), \\ &= Pr(\wp_{eNB} + G_{UE} + \xi - 10\eta \log d - I_{UE} - N > T), \\ &= Q\left(\frac{T + N + I_{UE} - \wp_{eNB} - G_{UE} + 10\eta \log d}{\sigma}\right). \end{aligned} \tag{1}$$

where d is the distance between eNB and UE and $Q(x) = \frac{1}{2\pi} \int_x^\infty \exp(\frac{-x^2}{2})dx$. The authors suggest that for every point with $pc_d \geq$ 0.5, the expected value of the received SINR at UE is greater than the decoding threshold T. Then, the coverage radius R^d_{cov} is the distance from eNB at which UE experiences pc_d = 0.5, such that all locations of the UE at a distance $d > R^d_{cov}$ from the eNB experience $pc_d <$ 0.5. Now, for a two hop cellular network, the probability of correct decoding in DL is given by:

$$\begin{aligned} pc^d &= pc^d_b . pc^d_a, \\ &= Pr(SINR_{eNB-RN} > T) \times Pr(SINR_{RN-UE} > T), \\ &= Q\left(\frac{T + N + I^d_{RN} - \wp_{eNB} - G_{RN} + 10\eta \log R^d_b}{\sigma_b}\right) \\ &\times Q\left(\frac{T + N + I_{UE} - \wp_{RN} - G_{UE} + 10\eta \log R^d_a}{\sigma_a}\right). \end{aligned} \tag{2}$$

where R^d_b and R^d_a are the distances from eNB to RN and RN to UE. For this two-hop cellular network, coverage radius R^{d*}_{cov} is the maximum distance from eNB at which transmission via a RN results in pc^d = 0.5. Authors in [3] suggest that the optimal location to deploy a RN must lie on the line joining eNB and UE. Thus, $R^{d*}_{cov} = R^{d*}_b + R^{d*}_a$ where, R^{d*}_b is the optimal RN placement radius in DL and R^{d*}_a is the RN-UE distance in DL such that $pc^d = pc^d_b . pc^d_a$ = 0.5 [5].

However, UL transmission scenario in a cellular system is asymmetrical compared to DL in terms of maximum transmit power and hence, coverage. The maximum transmit power of UEs in UL is less compared to the maximum transmit power of eNB in DL. Hence, the optimal relay placement with only DL scenario into consideration may adversely affect the UL performance. Deploying a relay at R^{d*}_b may not even support two way communication (as the probability of correct decoding in UL (pc^u) is likely to fall below 0.5). Therefore, we formulate a joint optimization problem using DL and UL transmission scenario and find the optimal location for relay

TABLE I
List of Notations

Symbol	Description
M, N_R and N_{UE}	Number of eNBs, RNs and UEs in the network
N_{sc}	Number of subcarriers in the network
R_b	Distance between RN and eNB (backhaul link)
R_a	Distance between RN and UE (access link)
P_{eNB}, P_{RN}, P_{UE}	Maximum transmit power of eNB, RN and UE
$\wp_{eNB}, \wp_{RN}, \wp_{UE}$	Maximum transmit power of eNB, RN and UE on each subcarrier
ξ	Log-Normal Shadowing parameter
σ_a, σ_b	Standard Deviation of Shadowing for access and backhaul link
pc^d, pc^u	Probability of correct decoding for DL and UL
pc^d_b, pc^d_a	Probability of correct decoding for backhaul and access link in DL
pc^u_b, pc^u_a	Probability of correct decoding for backhaul and access link in UL
$SINR^d_b$, $SINR^d_a$	SINR on backhaul and access link in DL
$SINR^u_b$, $SINR^u_a$	SINR on backhaul link and access link in UL
G_{UE}, G_{RN} and G_{eNB}	Antenna gains of UE, RN and eNB
I_{UE}, I^d_{RN}	Interference at UE and RN in DL
I_{eNB}, I^u_{RN}	Interference at eNB and RN in UL
T	Threshold value of SINR
N	Noise level
p_{act}	probability of subcarrier activity
η	path loss exponent

placement. For the UL transmission scenario of two hop relay networks, probability of correct decoding is given by:

$$
\begin{aligned}
pc^u &= pc_a^u . pc_b^u, \qquad (3)\\
&= Pr(SINR_{UE-RN} > T) \times Pr(SINR_{RN-eNB} > T),\\
&= Q\left(\frac{T + N + I_{RN}^u - \wp_{UE} - G_{RN} + 10\eta \log R_a^u}{\sigma_a}\right)\\
&\times Q\left(\frac{T + N + I_{eNB} - \wp_{RN} - G_{eNB} + 10\eta \log R_b^u}{\sigma_b}\right).
\end{aligned}
$$

It can be seen from (2) and (3) that for a given value of pc, R_a is a function of R_b. Thus, there is a trade-off between the values of R_a and R_b. Therefore, we need to determine the value of R_b which maximizes the cell coverage such that the probability of correct decoding in both UL and DL is greater than or equal to 0.5 (i.e., $pc^u \geq 0.5$ and $pc^d \geq 0.5$). Therefore, the optimal relay placement location (R_b^*) is given as:

$$R_b^* = \underset{R_b \in (0, R_b^{max})}{\arg\max} \; \min((R_b + R_a^u), (R_b + R_a^d)) \text{ s. t.} \qquad (4)$$

$$\min\ (pc_b^u . pc_a^u, pc_b^d . pc_a^d) = 0.5 \qquad (5)$$

where $R_b^{max} = \min\ (R_b^{umax}, R_b^{dmax})$ and, R_b^{umax} and R_b^{dmax} are the maximum possible relay placement distances for UL and DL. This implies that the value of pc_b^u is 0.5 when RN is placed at R_b^{umax} and the value of pc_b^d is 0.5 when RN is placed at R_b^{dmax}. If R_{cov}^* is the maximum coverage extension and R_b^* is the optimal relay placement. Then, R_a^* is given as $R_{cov}^* - R_b^*$ and the number of relays (N) is given by [5]:

$$N_R = \lceil \frac{\pi}{\sin^{-1}(\frac{R_a^*}{R_b^*})} \rceil. \qquad (6)$$

B. Analysis in Scenario without Interference

For an interference-free scenario, we neglect the interferences received from neighbouring cells. Therefore, $I_{UE} = I_{RN}^d = I_{RN}^u = I_{eNB} = 0$. We determine the value of R_b^*, R_{cov}^* and N using following steps:

1) Determine the value of R_b^{umax} and R_b^{dmax}. And, $R_b^{max} = \min\ (R_b^{umax}, R_b^{dmax})$.
2) For $R_b = 1$, compute R_a^u such that $pc_u^b . pc_u^a = 0.5$. Then, assign $R_{cov}^u = R_b + R_a^u$.
3) For $R_b = 1$, compute R_a^d such that $pc_d^b . pc_d^a = 0.5$. Then, assign $R_{cov}^d = R_b + R_a^d$.
4) $R_{cov}^{(0)} = \min\ (R_{cov}^u, R_{cov}^d)$.
5) Repeat the Steps 2 and 3 $\forall R_b \in (1, R_b^{max}]$ and form the array $\mathbf{R}_{cov}$.
6) Finally compute $R_{cov}^* = \max\ (\mathbf{R}_{cov})$ and optimal relay placement distance R_b^* is the value of R_b corresponding to R_{cov}^*. Also, $N_R = \lceil \frac{\pi}{\sin^{-1}(\frac{R_a^*}{R_b^*})} \rceil$.

C. Analysis in Interference Scenario

We compute the ICIs in DL and UL separately since the possible interferers in DL and UL are different. For DL transmission, I_{RN}^d at the reference RN and I_{UE} at the reference UE are computed as shown in Fig. 1. The total interference power received at the reference RN is the sum of intereference powers from neighbouring eNBs. From Fig. 1, it can be seen that there are 6 neighbouring eNBs. Therefore,

$$I_{RN}^d = \sum_{i=2}^{7} I_{rd}^i = \sum_{i=2}^{7} p_{act}(\wp_{eNB} + G_{RN}) d_i^{-\eta}. \qquad (7)$$

where I_{rd}^i and d_i are the interference power and distance from the i^{th} eNB to the reference RN during DL transmission. Also,

$$I_{UE} = \sum_{i=2}^{7} I_u^i = \sum_{i=2}^{7} \frac{p_{act}}{N_R} \sum_{r=1}^{N} (\wp_{RN} + G_{UE}) d_{i,r}^{-\eta}. \qquad (8)$$

Here, I_u^i is the interference power received at the reference UE from RNs of the i^{th} neighboring cell and $d_{i,r}$ is the distance between the reference UE and the r^{th} RN of the i^{th} neighboring cell. For simplicity of analysis, we consider only path loss during calculation of ICIs.

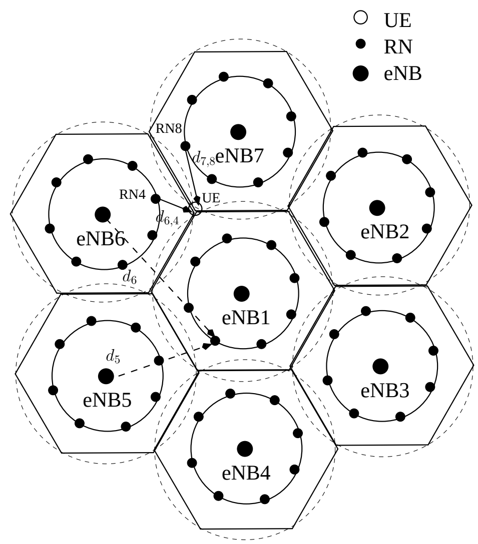

Fig. 1. Interference scenario in DL: Dashed lines denote distances d_i from the eNB of i^{th} neighboring cell to the reference RN. Solid lines denote distances $d_{i,r}$ from r^{th} RN of i^{th} neighboring cell to the reference UE.

Similarly, we compute the interference power I_{eNB} at the reference eNB during UL as shown in Fig. 2 The total interference power received at the reference eNB is the sum of interference powers from RNs of the neighboring cells. So,

$$I_{eNB} = \sum_{i=2}^{7} I_e^i = \sum_{i=2}^{7} \frac{p_{act}}{N_R} \sum_{r=1}^{N} (\wp_{RN} + G_{eNB}) de_{i,r}^{-\eta}. \qquad (9)$$

Here, I_e^i is the interference power received at the reference eNB from RNs of the i^{th} neighboring cell and $de_{i,r}$ is the distance between the reference eNB and the r^{th} RN of the i^{th} neighboring cell. Also, I_{RN}^u is the interference power received at the reference RN from UEs of the neighboring cells. To calculate I_{RN}^u, we assume that UEs are uniformly distributed in the cell. There can be maximum one UE in the neighboring cell 'i' which interferes with the transmission of the reference UE. If N_{UE} is the total number of UEs in each cell then,

$$I_{RN}^u = \sum_{i=2}^{7} I_{ru}^i = \sum_{i=2}^{7} \frac{p_{act}}{N_{UE}} \sum_{u=1}^{N_{UE}} (P_{UE} + G_{RN}) dr_{i,u}^{-\eta}. \qquad (10)$$

where I^i_{ru} is the interference power from UEs of the i^{th} neighboring cell to the reference RN and $dr_{i,u}$ is the distance between the reference RN and the u^{th} UE of i^{th} neighboring cell. We assume that the subcarrier allocation algorithm is such that each subcarrier has probability $1/N_{UE}$ of being alloted to a UE in a cell which justifies the factor $1/N_{UE}$ in (10).

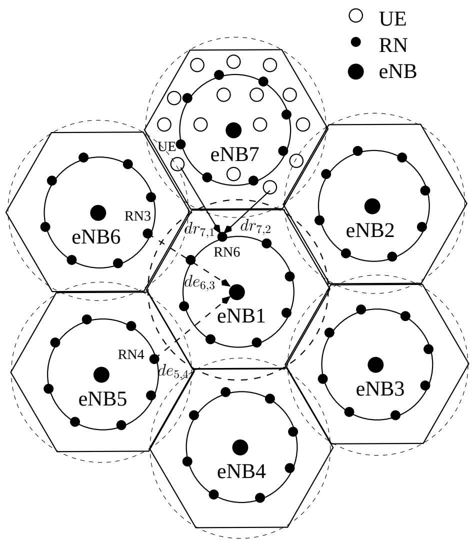

Fig. 2. Interference scenario in UL: Dashed lines denote distances $de_{i,r}$ from r^{th} RN of i^{th} neighboring cell to the reference eNB. Solid lines denote distances $dr_{i,u}$ from u^{th} UE of i^{th} neighboring cell to the reference RN.

In case of interference scenario, SINR at the receiver is not only dependent on transmit power and antenna gains but also on the number of RNs in each cell and the distance between transmitter and receiver. Therefore, the value of R_{cov} is required to determine R_a for a given value of R_b. Therefore, we use the modified version of the iterative algorithm proposed in [5] to calculate the optimal relay placement location. The algorithm uses the value of R_{cov} calculated from Section III-B to compute the value of R^u_a and R^d_a as a function of relay placement distance R_b. Then, we determine the maximum value of $min(R_b + R^u_a, R_b + R^d_a)$ for all possible values of R_b and assign this as the new value of R_{cov}.

Algorithm I: Iterative calculation of R_b, R_{cov} and N

$R^{(1)}_{cov} \leftarrow R^{(noint)}_{cov}$:value of R^*_{cov} obtained from Section III-B
$R^{(0)}_{cov} \leftarrow 0$
$N^{(1)}_R = N^{(noint)}_R$:value of N_R obtained from Section III-B
$i \leftarrow 1$
while $|R^{(i)}_{cov} - R^{(i-1)}_{cov}| > \epsilon$ **do**
  Comment : For Downlink Scenario
  for each $R_b \in (0, R^{(i)}_{cov}]$
    $\mathbf{R}^d_{cov} \leftarrow \{\phi\}$
    Compute I^d_{RN} and I_{UE}
    $pc^d_b = Q\left(\frac{T+N+I^d_{RN}-\wp_{eNB}-G_{RN}+10\eta\log R_b}{\sigma_b}\right)$
    flag $= 0$
    if $pc^d_b < 0.5$ **then**
      set flag = 1 and break the loop
    end if
    $pc^d_a = Q\left(\frac{T+N+I_{UE}-\wp_{RN}-G_{UE}+10\eta\log R^d_a}{\sigma_a}\right)$
    Solve $pc^d_a.pc^d_b$ = 0.5 for R^d_a
    Append R^d_a + $R_b \leftarrow \mathbf{R}^d_{cov}$
  end for
  if flag $= 1$ **then**
    Append 0s to $\mathbf{R}^d_{cov}$ to fill the remaining array
  end if
  Comment : For Uplink Scenario
  for each $R_b \in (0, R^{(i)}_{cov}]$
    $\mathbf{R}^u_{cov} \leftarrow \{\phi\}$
    Compute I^u_{RN} and I_{eNB}
    $pc^u_b = Q\left(\frac{T+N+I_{eNB}-\wp_{RN}-G_{eNB}+10\eta\log R_b}{\sigma_b}\right)$
    flag $= 0$
    if $pc^u_b < 0.5$ **then**
      set flag = 1 and break the loop
    end if
    $pc^u_a = Q\left(\frac{T+N+I^u_{RN}-\wp_{UE}-G_{RN}+10\eta\log R^u_a}{\sigma_a}\right)$
    Solve $pc^u_a.pc^u_b$ = 0.5 for R^u_a
    Append R^u_a + $R_b \leftarrow \mathbf{R}^u_{cov}$
  end for
  if flag $= 1$ **then**
    Append 0s to $\mathbf{R}^u_{cov}$ to fill the remaining array
  end if
  $\mathbf{R}_{cov} = \min\ (\mathbf{R}^d_{cov}, \mathbf{R}^u_{cov})$
  $i \leftarrow i + 1$
  $R^{(i)}_{cov} = \max\ \mathbf{R}_{cov}$
  $R^{(i)}_b = \arg\max\ \mathbf{R}_{cov}$
  $N^{(i)}_R = \left\lceil \frac{\pi}{\sin^{-1}\left(\frac{R^{(i)}_{cov}-R^{(i)}_b}{R^{(i)}_b}\right)} \right\rceil$
end while

IV. Results and Inferences

In this section, we provide the numerical results corresponding to the analysis of optimal relay placements in Section III-B and III-C. The value of maximum transmit power and antenna gains for eNB, RN and UE are based on LTE-A specifications [6]. The value of Noise level (N) is considered to be -100 dBm, decoding threshold (T) is 4.2 dB, number of UEs (N_{UE}) is 120, and number of subcarriers N_{sc} is 512. Standard deviation of shadowing on access (σ_a) and backhaul (σ_b) links are assumed to be 6 and 3 dB respectively. Also, probability of subcarrier activity p_{act} and path loss exponent η are taken to be 1 and 3.5 respectively. We assume that there is equal power division amongst subcarrier. Therefore, $\wp_{eNB} = \frac{P_{eNB}}{N_{sc}\times p_{act}}$. The subcarrier allocation algorithm is such that each RN gets equal number of subcarriers. Hence, $\wp_{RN} = \frac{P_{RN}\times N_R}{N_{sc}\times p_{act}}$. Also, each subcarrier has an equal probability of being assigned to a UE, as mentioned in Section III-C. So, we compute $\wp_{UE}$ as $\frac{P_{UE}\times N_{UE}}{N_{sc}\times p_{act}}$.

In Fig. 3, we plot the value of extended cell radius (R_{cov}) against relay placement radius (R_b) for interference-free scenario with both DL and UL into consideration. It can be seen from the figure that the optimal radial position for

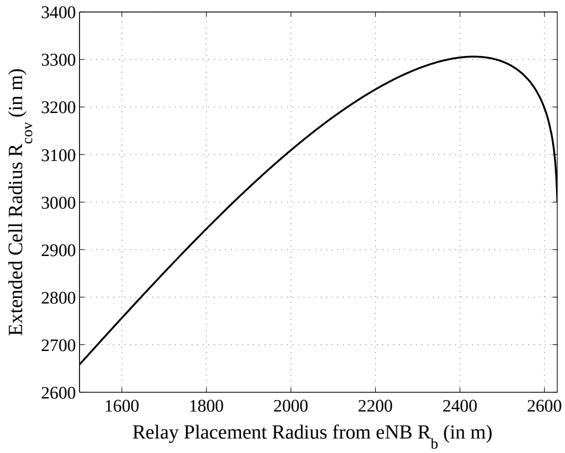

Fig. 3. Plot of extended cell radius (R_{cov}) versus RN placement distance (R_b) for DL/UL scenario wihtout interference into consideration

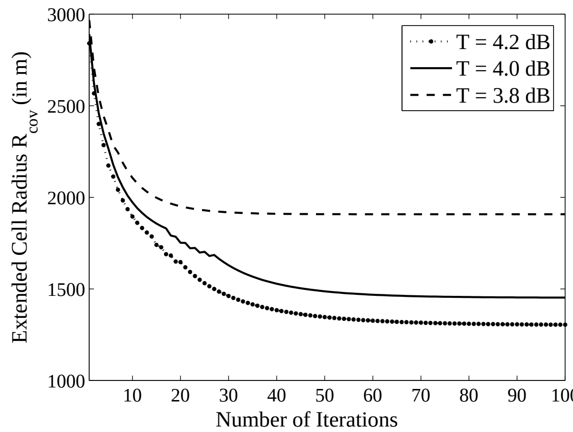

Fig. 5. Plot showing convergence of extended cell radius (R_{cov}) for Algorithm-I to evaluate the optimal RN placement location for DL/UL scenario with interference into consideration for varying decoding thresholds

relay placement (R_b^*) is 2.43 km, R_{cov}^* is 3.3 km and the number of RNs required (N_R) is 9 (from (6)).

In order to find the optimal relay placement with ICI into consideration, we use Algorithm I. The value of R_{cov}^* and N_R calculated for intereference-free scenario are fed as the initial values in Algorithm I (i.e., $R_{cov}^{(noint)}$ = 2.43 km and $N^{(noint)}$ = 9). For ϵ = 0.01 and p_{act} =1, the value of R_{cov} converges to 1.3 km (Fig. 4). The corresponding value of optimal RN placement location is 0.775 km and the number of RNs required is 5.

In Fig. 4, we also observe the impact of p_{act} on R_{cov}. p_{act} = 1 represents a worst case scenario where all the subcarriers in a cell are being used. Therefore, reduction in the value of p_{act} causes lower interference on the reference cell and hence, increases the cell coverage. Fig. 5 illustrates the convergence of R_{cov} for various values of decoding threshold. We can observe from the figure that the cell coverage radius increases with the decrease in decoding threshold.

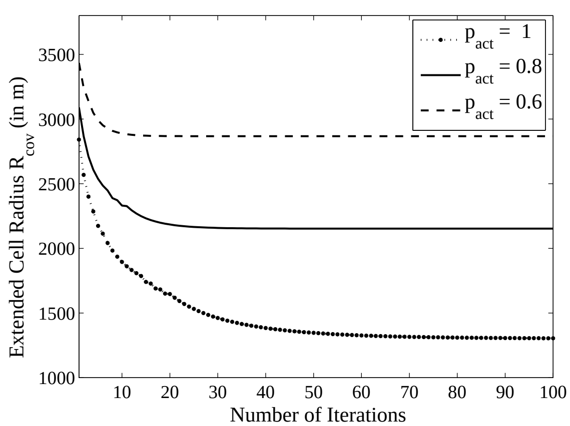

Fig. 4. Plot showing convergence of extended cell radius (R_{cov}) for Algorithm-I to evaluate the optimal RN placement location for DL/UL scenario with interference into consideration for varying p_{act}

V. Conclusions

In this paper, we have suggested that the optimal relay placement location evaluated with only DL into consideration may degrade the UL performance. This is because of the fact that DL and UL transmission scenarios are asymmetrical in terms of maximum transmit power and hence, coverage. Therefore, it is essential to consider both DL and UL transmission scenarios to calculate the optimal RN placement location for cellular coverage extension. In this paper, we have proposed the algorithms to calculate the optimal RN placement location in scenarios with and without intereference. We have also illustrated the effect of decoding threshold and probability of subcarrier activity on cell radius. Though, we have simulated the algorithms with LTE-A specifications, they can be applied to non-LTE-A based cellular networks as well. The optimal relay placement location and the extended coverage radius calculated in this paper can be practically used as a system design parameter in cellular systems.

References

[1] 3GPP TR 36.814, “Further Advancements for E-UTRA Physical Layer Aspects,” March 2010.

[2] 3GPP TR 36.913, “Requirements for Further Advancements for Evolved Universal Terrestrial Radio Access (E-UTRA),” March 2009.

[3] B. Lin, P. H. Ho, L. L. Xie, and X. Shen, “Optimal Relay Station Placement in IEEE 802.16j Networks,” in *International Conference on Wireless Communications and Mobile Computing*, 2007, pp. 25–30.

[4] C. Y. Chang, C. T. Chang, M. H. Li, and C. H. Chang, “A Novel Relay Placement Mechanism for Capacity Enhancement in IEEE 802.16j WiMAX Networks,” in *proceedings of IEEE International Conference on Communications*, 2009.

[5] G. Joshi and A. Karandikar, “Optimal Relay Placement for Cellular Coverage Extension,” in *NCC*, January 2011.

[6] 3GPP TSG-RAN WG1 #54bis R1-084026, “Text Proposal for Evaluation Methodology,” 2008.