

A Strategy for Optimal Resource Allocation in LTE Advanced Relay Networks under Statistical QoS Constraints

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ABSTRACT: The LTE-Advanced, on relay technologies due to large traffic volumes will face a challenge. Standards of LTE-Advanced networks is now aiming towards to achieve a high capacity and high speed communication system. To overcome the challenge, relay network will be the new architecture for LTE-Advanced networks. The LTE-A main goal is to provide a high data rate and bandwidth. In this paper, we research about the resource allocation for LTE-A networks under statistical QoS constraints. Subcarrier allocation and power allocation strategies are derived to maximize the effective capacity (EC) of LTE-A relay system. The allocations are optimized individually and our result suggests that the strategies are depended heavily on underlying QoS constraints. In the SINR regime, when less QoS constraints the Base Stations (BS) and Relay Stations (RS) tends to allocate all the power to available subcarriers in case of low SINR. In case of high SINR, regardless of QoS constraints the Base Stations (BS) and Relay Stations (RS) will allocate power equally among available subcarriers achieving the optimal solution is necessitating the use of sub optimal techniques. Simulation results are shown to compare the performance of proposed system.

KEYWORDS: LTE Advanced, EC, SINR, Relay Networks, Power Allocation, Delay Analysis, Resource Allocation.

I. INTRODUCTION

As the work on first LTE is coming to an end, the focus is now gradually shifting towards the further evolution of LTE, referred to as LTE-Advanced. One of the goals of this evolution is to reach and even surpass the requirements on IMT-Advanced, as currently being defined by ITU-R. These requirements will include further significant enhancements in terms of performance and capability compared to current cellular systems, including the first release of LTE. Since a significant portion of the video traffic is delay-sensitive with stringent quality of service (QoS) constraints, the predictions clearly suggest that future mobile data networks will face the dual challenge of supporting large traffic volumes and providing reliable service for applications of heterogeneous service constraints. Meanwhile, relay networks with a deployment of both high power base stations (BSs) and low power relay nodes (RNs) sharing the same spectrum resources have been recently adopted in the 4G mobile broadband system—3GPP LTE-A networks. Resource allocation techniques for multiuser Orthogonal Frequency Division Multiplexing (OFDM) are of two types: fixed and dynamic. Fixed resource allocation techniques fail to exploit multiuser diversity resulting in poor system performance. On the other hand, dynamic resource allocation techniques allocate resources (subcarriers and time slots) taking into account the users' current channel conditions. The introduction of low power relay nodes changes the traditional homogeneous cellular network to a heterogeneous one where nodes with different transmission power levels are overlaid with each other, and creates both opportunities and challenges. Since both the access link and the backhaul link share the same spectrum resource, resource allocation between these two links should be optimized to ensure maximal utilization of the overall system resource. In LTE-A relay networks, base stations and relay nodes share the

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same spectrum resource to serve mobile stations (MSs). In this way, the overall information-theoretic capacity of a heterogeneous network can be significantly increased due to the “cell-splitting” gain.

II. BACKGROUND

In order to address the QoS requirements of delay-sensitive traffic, in this paper, a metric is adopted to capture the asymptotic decay-rate of buffer occupancy:

$$\theta = - \lim_{x \rightarrow \infty} \log \Pr\{L > x\} / x \dots\dots\dots(1)$$

where L is the equilibrium queue-length distribution of the buffer present at the transmitter. The parameter θ reflects the perceived quality of a wireless link. A larger θ reflects a better connection or a tighter service constraint. This metric is closely tied to the concept of effective bandwidth, which has been studied extensively in the context of wired networks. Given a specific arrival process, the effective bandwidth characterizes the minimum bandwidth required for the communication system to meet a certain QoS requirement θ . The metric θ is also related to the dual concept of effective capacity popularized by Wu and Negi. Unlike wired connections where the service rates are typically constant, wireless channels are inherently unreliable and the associated service rates are usually time-varying. Assuming a constant flow of incoming data, the effective capacity characterizes the maximum arrival rate that a wireless system can support subject to a QoS requirement θ . When θ approaches zero, the effective capacity converges to the Shannon capacity. Relay networks have been heavily investigated in the information theory society. Most of the work in the relay network literature focuses on delay-insensitive traffic where the channel capacity is maximized under the transmission power constraint. A cross-layer approach is introduced to investigate resource allocation strategies for relay networks under QoS constraints. To be specific, power allocation schemes are characterized to maximize the effective capacity of relay networks where the relay node has no buffer. The impact of the quality of service (QoS) constraint on the optimal power allocation is investigated in the single carrier point to point system. The result reveals that the optimal power allocation strategy depends heavily on both the underlying QoS constraint and the instantaneous channel state information (CSI). However, in our paper, we consider the problem of maximizing the effective capacity of LTE-A relay networks under channel statistics feedback. A joint subcarrier pairing and power allocation for OFDM with decode and forward (DF) relay is investigated. It is assumed that all the subcarriers used at the base station (BS) can be fully reused at the relay node (RN). This is very different from what we are investigating for LTE-A relay networks. Furthermore, the total power constraint of both BS and RN is assumed rather than that of the individual power constraint at BS and RN respectively. The quality of service (QoS) aspect is not investigated, the authors imposed individual QoS constraints at each node and provide a characterization of the end to end delay violation probability for a two-hop relay system. A multi-cell OFDMA system with decode-and-forward relaying is considered. The delay sensitive mobile station is characterized by its requirement of the minimum constant data rate. However, in our paper, we will characterize the optimal power allocation strategy for delay-sensitive traffic based on the QoS metric θ which can be related to the delay-violation probability. Furthermore, we will introduce low complexity resource allocation strategies with close performance to the optimal one. These work certainly improve our understanding of delay sensitive traffic over relay networks; however, the knowledge on this topic is far from being fully developed.

III. RESEARCH WORK

The research of the paper is the following.

1. To characterize the effective capacity of a LTE-A relay network based on large deviation principle. The effective capacity is a function of the subcarrier allocation scheme as well as the power allocation scheme for both the access link as well as the backhaul link of the underlying OFDMA relay network.
2. To introduce an optimal resource allocation strategy via dual decomposition, which has low computational complexity compared to the exhaustive search method. The closed-form expressions of the optimal power and subcarrier allocation strategy are derived given the underlying quality of service (QoS) constraint under the assumption of the Rayleigh fading channel in the low SINR regime.

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3. We identify the characteristics of the effective capacity of the LTE-A relay network and characterize the properties of the optimal resource allocation strategies. The optimal subcarrier allocation strategy tends to equate the effective capacity of the access link with that of the backhaul link while the optimal power allocation strategy follows a water-filling strategy. The water level depends on underlying QoS constraint θ_0 .
4. To decompose the original resource allocation problem into two sub-problems: subcarrier allocation and power allocation, we introduce a low-complexity suboptimal resource allocation strategy. Furthermore, the optimal power allocation strategy as a function of the underlying quality of service (QoS) constraint is investigated in the low and high SINR regime respectively, which is largely unexplored in the literature. It is also verified that the introduced resource allocation strategy performs close to the optimal one with less complexity via numerical simulation. It is important to note that resource allocation in OFDMA systems has been heavily investigated in the literature. Most the work in the field focus on maximizing physical layer capacity of the system without the consideration of effective capacity.

IV. PROPOSED METHODOLOGY AND DISCUSSION

LTE-A relay network is shown, in LTE-A networks, a relay node is associated with a donor base station. A relay node is no different from a mobile station. Due to relay node, mobile stations can choose to be associated with either the base station or the relay node. If once a MS is chosen to be associated with the base station, it cannot receive any kind of data from relay nodes. On the other hand, once a mobile station is chosen to be associated with the relay node, it cannot receive signals from base station directly.

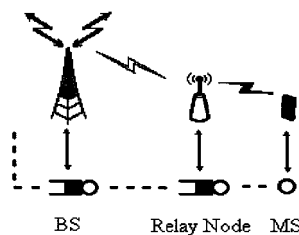


Fig. 1. LTE-A relay network and its queuing abstraction through wireless link.

For those mobile stations connected to the RN, the traffic reaches the buffer at the base station before sending to the relay node. Upon reception of the signals, the relay node decodes the data and forwards it to the corresponding mobile station. In LTE-A systems, OFDMA is used for multiple access where each subcarrier is exclusively assigned to only one user at a time to eliminate the inter-user interference. Since both the base station and the relay node share the same radio spectrum and the relay node is a half-duplex node only one can send data at each time, each subcarrier of the system is assigned to either the backhaul (BS-RN) link or the access link (RN-MS).

Power allocation for a fixed subcarrier

After identifying the subcarrier allocation strategy, the base station and relay node will need to maximize the corresponding effective capacity based on power allocation. For a fixed subcarrier allocation, the optimization problem introduced can be rewritten as

$$\begin{aligned}
 & \max \quad r \\
 & \text{s.t.} \quad \sum_{n \in \Omega_1} \alpha(\theta_0, P_{1n}, \beta_{1n}) \geq r \\
 & \quad \quad \sum_{n \in \Omega_2} \alpha(\theta_0, P_{2n}, \beta_{2n}) \geq r \\
 & \quad \quad \sum_{n \in \Omega_1} P_{1n} \leq P_1 \\
 & \quad \quad \sum_{n \in \Omega_2} P_{2n} \leq P_2
 \end{aligned}$$

This optimization problem is equivalent to finding the maximum of the following cost function where μ, λ are Lagrange multipliers. By setting each derivative to 0 we can obtain the conditions for the optimal power allocation strategies.

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$$L(r, \mathbf{P}, \boldsymbol{\mu}, \boldsymbol{\lambda}) = \sum_{i=1}^2 \mu_i \left(\sum_{n \in \Omega_i} \alpha(\theta_0, P_{1n}, \beta_{1n}) - r \right) + \sum_{i=1}^2 \lambda_i \left(P_i - \sum_{n \in \Omega_i} P_{in} \right) + r, \quad (26)$$

where μ, λ are Lagrange multipliers. By setting each derivative to 0 we can obtain the conditions for the optimal power allocation strategies.

$$\begin{aligned} \frac{\partial L}{\partial P_{1n}} - \mu_1 \frac{\partial \alpha(\theta_0, P_{1n}, \beta_{1n})}{\partial P_{1n}} - \lambda_1 &= 0, \\ \frac{\partial L}{\partial P_{2n}} - \mu_2 \frac{\partial \alpha(\theta_0, P_{2n}, \beta_{2n})}{\partial P_{2n}} - \lambda_2 &= 0. \end{aligned} \quad (27)$$

We can certainly plug in the expression of the effective capacity to obtain the optimality conditions for the general case. However, the expression will contain functions that are computationally complex. Furthermore, not much intuition can be obtained through those complicated expressions. In order to gain the intuition of the optimal resource strategy, we analyse the optimal power allocation scheme in both high SINR and low SINR regimes. High SINR Regime: Considering the case where the system is operating in the high SINR regime where $\{\gamma_{1n}P_{1n}, \gamma_{2n}P_{2n}\} \gg (N_0W + I)$, then becomes

$$\begin{aligned} \frac{\partial L}{\partial P_{1n}} &= \frac{\mu_1 W}{P_{1n}} \frac{E[e^{-\theta_0 P_{1n}}]}{E[e^{-\theta_0 P_{1n}}]} - \lambda_1 \\ \frac{\partial L}{\partial P_{2n}} &= \frac{\mu_2 W}{P_{2n}} \frac{E[e^{-\theta_0 P_{2n}}]}{E[e^{-\theta_0 P_{2n}}]} - \lambda_2, \end{aligned} \quad (28)$$

where $\text{rin} = WT \log_2 1 + \gamma_{in} P_{in} \Gamma(N_0W + I)$ for $i = 1, 2$. Set the partial derivatives to be 0 we can obtain the optimal

$$P_{1n}^* = \frac{\mu_1}{\lambda_1} W, \quad P_{2n}^* = \frac{\mu_2}{\lambda_2} W. \quad (29)$$

It is important to find that the optimal power allocation in the high SINR regime is not a function of the quality of service constraint θ_0 . In fact, we can immediately see that the transmit power is uniformly spread over the assigned subcarriers, i.e.,

$$P_{1n}^* = \frac{P_1}{|\Omega_1|}, \quad P_{2n}^* = \frac{P_2}{|\Omega_2|}.$$

Not surprisingly, this power allocation strategy is also optimal for Shannon capacity in the high SINR regime, this is because in the high SINR regime, the capacity is insensitive to the received power and varying the amount of transmit power as a function of the channel state yields a minimal gain. Low SINR Regime: When the system is operating in the low SINR regime, the expression of the effective capacity can be expressed. Accordingly, the partial derivatives of the cost function with respect to the power allocation can be expressed as

$$\begin{aligned} \frac{\partial L}{\partial P_{1n}} &= \frac{\mu_1}{\theta_0 T} \frac{\partial \log \left(1 + \frac{\theta_0 WT \beta_{1n} P_{1n}}{\Gamma(N_0W + I)} \right)}{\partial P_{1n}} - \lambda_1 \\ \frac{\partial L}{\partial P_{2n}} &= \frac{\mu_2}{\theta_0 T} \frac{\partial \log \left(1 + \frac{\theta_0 WT \beta_{2n} P_{2n}}{\Gamma(N_0W + I)} \right)}{\partial P_{2n}} - \lambda_2. \end{aligned}$$

Let $\partial L / \partial P_{1n} = 0$ and $\partial L / \partial P_{2n} = 0$, the optimal power allocation can be expressed as

$$\begin{aligned} P_{1n}^* &= \frac{1}{\theta_0 T} \left[\frac{\mu_1}{\lambda_1} - \frac{\Gamma(N_0W + I)}{W \beta_{1n}} \right]^+ \\ P_{2n}^* &= \frac{1}{\theta_0 T} \left[\frac{\mu_2}{\lambda_2} - \frac{\Gamma(N_0W + I)}{W \beta_{2n}} \right]^+, \end{aligned} \quad (30)$$

where μ_1, μ_2, λ_1 and λ_2 are the Lagrangian multipliers, which need to ensure the system to meet the total power constraints. It is important to note that the optimal power allocation strategy expressed is exactly the same as that expressed with different Lagrangian multipliers. Let $x_1 = \mu_1 / \lambda_1$ and $x_2 = \mu_2 / \lambda_2$. It can be seen from that the optimal power allocation strategy follows a water-filling structure where the “water levels”, x_1 and x_2 , not only depend on the total transmit powers available at the transmitters but also depend on the QoS constraint θ_0

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$$\sum_{n \in \Omega_1} \left[\frac{\mu_1}{\lambda_1} - \frac{\Gamma(N_0W + I)}{W\beta_{1n}} \right]^+ = \theta_0 T P_1,$$

$$\sum_{n \in \Omega_2} \left[\frac{\mu_2}{\lambda_2} - \frac{\Gamma(N_0W + I)}{W\beta_{2n}} \right]^+ = \theta_0 T P_2. \quad (31)$$

As the QoS constraint becomes more stringent, i.e., θ_0 increases, the overall effective power increases and the transmitter will tend to use more subcarriers even in the low SINR regime. This intuition can be seen more clearly as well as the simulation results shown. We introduce a new methodology to solve the Lagrangian multipliers in the low SINR regime. Let

$$f_1(x_1) = \sum_{n \in \Omega_1} \frac{1}{\theta_0 T} \left[x_1 - \frac{\Gamma(N_0W + I)}{W\beta_{1n}} \right]^+ - P_1$$

Note that if $f_1(x^*) = 0$, x^*

is the solution to (31). Accordingly, if we could find the solution to $f_1(x_1) = 0$, we can substitute the solution x^* to (30) to obtain the optimal power allocation scheme P^*_{1n} for the base station. The optimal power allocation strategy for the relay node, P^*_{2n} , can be found using the same methodology based on

$$f_2(x_2) = \sum_{n \in \Omega_2} \frac{1}{\theta_0 T} \left[x_2 - \frac{\Gamma(N_0W + I)}{W\beta_{2n}} \right]^+ - P_2.$$

It is easy to show that both $f_1(x_1)$ and $f_2(x_2)$ are non-decreasing functions.

Let $\beta_{1\min} = \min_{\beta_{1n} \in \Omega_1} \{\beta_{1n}\}$, $\beta_{1\max} = \max_{\beta_{1n} \in \Omega_1} \{\beta_{1n}\}$, $\beta_{2\min} = \min_{\beta_{2n} \in \Omega_2} \{\beta_{2n}\}$, and $\beta_{2\max} = \max_{\beta_{2n} \in \Omega_2} \{\beta_{2n}\}$. Let x^*_1 and x^*_2 be the solutions to $f_1(x_1) = 0$ and $f_2(x_2) = 0$. Based on total power constraint, we have the following ranges of x^*_1 and x^*_2

$$x_{1\min} = \frac{\Gamma(N_0W + I)}{W\beta_{1\max}} \leq x^*_1$$

$$\leq \frac{\theta_0 T P_1}{|\Omega_1|} + \frac{\Gamma(N_0W + I)}{W\beta_{1\min}} = x_{1\max},$$

$$x_{2\min} = \frac{\Gamma(N_0W + I)}{W\beta_{2\max}} \leq x^*_2$$

$$\leq \frac{\theta_0 T P_2}{|\Omega_2|} + \frac{\Gamma(N_0W + I)}{W\beta_{2\min}} = x_{2\max}. \quad (32)$$

Based on the bounds of the “water levels” expressed in (32), we can show the following result for the optimal power allocation strategy in the large θ_0 regime. *Theorem 3:* For the fixed total transmit power of P_1 and P_2 , as θ_0 increases, the optimal power allocation tends to be the equal power allocation among subcarriers at both the base station and the relay node. *Proof:* Let Ω_i be the set of subcarriers assigned to link i with $P^*_{in} > 0$. From the optimal power allocation strategy expressed in (30) and (32), for $n \in \Omega_1$, we have the following relation

$$P^*_{1n} \leq \frac{1}{\theta_0 T} \left(x_{1\max} - \frac{\Gamma(N_0W + I)}{W\beta_{1n}} \right)$$

$$= \frac{1}{\theta_0 T} \left(\frac{\theta_0 T P_1}{|\Omega_1|} + \frac{\Gamma(N_0W + I)}{W\beta_{1\min}} - \frac{\Gamma(N_0W + I)}{W\beta_{1n}} \right)$$

$$= \frac{P_1}{|\Omega_1|} + \epsilon_1,$$

$$\epsilon_1 \triangleq \frac{1}{\theta_0 T} \left(\frac{\Gamma(N_0W + I)}{W\beta_{1\min}} - \frac{\Gamma(N_0W + I)}{W\beta_{1n}} \right).$$

It is clear that ϵ_1 decreases as θ_0 increases. When θ_0 is sufficiently large, it can be seen that P^*_{1n} is upper-bounded by $P_1/|\Omega_1|$. On the other hand, from the total transmit power constraint we have

$$P_1 = \sum_{n \in \Omega_1} P^*_{1n} \leq |\Omega_1| \frac{P_1}{|\Omega_1|} \leq |\Omega_1| \frac{P_1}{|\Omega_1|} = P_1.$$

Above equation suggests that $\Omega_1 = \Omega_1$ and $P^*_{1n} = P_1/|\Omega_1|$, which means that the total transmit power of the base station is distributed equally among assigned subcarriers. The same procedure can be applied at the relay node to characterize the optimal power allocation strategy in the large θ_0 regime. Substituting the “water levels” of x^*_1 and x^*_2 into (30) we will be able to obtain the optimal power allocation strategy for the delay-sensitive traffic over the LTE-

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Arely network in the low SINR regime. *Complexity Analysis* The total number of all possible subcarrier allocation schemes is $O(2N)$ where N is the number of subcarriers in the system. For each subcarrier allocation scheme, the complexity of computing the power allocation is $O(N)$ considering the multiplication. In order to obtain the optimal resource allocation, we need to calculate the effective capacity for each subcarrier allocation, the complexity of which is also $O(N)$ in terms of the logarithm function and multiplication. To this end, the complexity of the exhaust search is $O(N2N)$, which is extremely high. The complexity of our proposed optimal method is much lower compared to the exhaust search methodology. If the ellipsoid method is used to update the Lagrange multipliers, in each iteration, the complexity of computing the subcarrier and power allocation are both $O(N)$. If the total number of iterations is M , then the complexity of our proposed optimal method is $O(MN)$. Our proposed suboptimal method can further decrease the computation complexity by decomposing the optimization problem into two sub-problems. The complexity of computing the subcarrier and power allocation are both $O(N)$, thus the total complexity is also $O(N)$, which is much lower than that of the exhaust search method.

V. RESULT ANALYSIS

Figures shows the results and simulated evaluation of a strategy for optimal resource allocation in LTE Advanced relay networks under statistical QoS constraints.

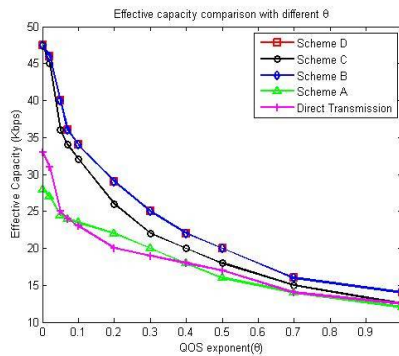


Fig:(a) Effective capacity comparison with different θ .

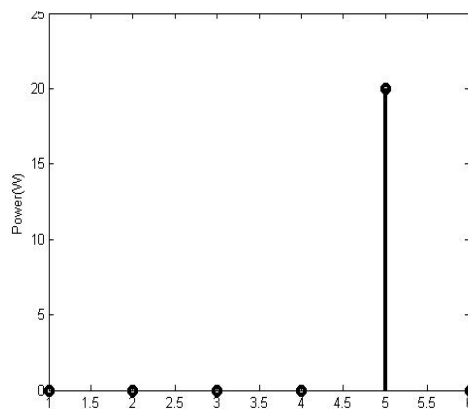


Fig:(b) Power allocation at BS when $\theta = 0.01$.

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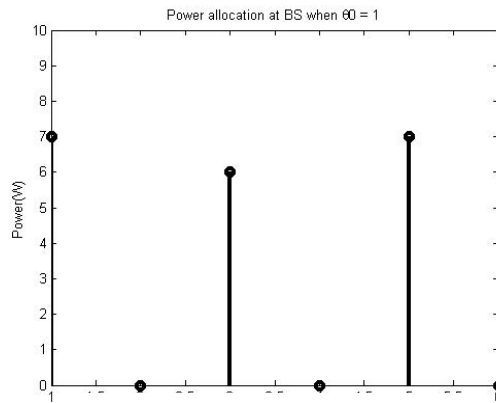


Fig:(c) Power allocation at BS when $\theta = 1$

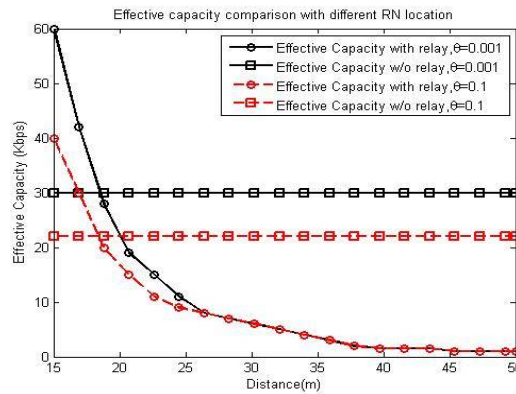


Fig:(d) Effective capacity comparison with different RN location.

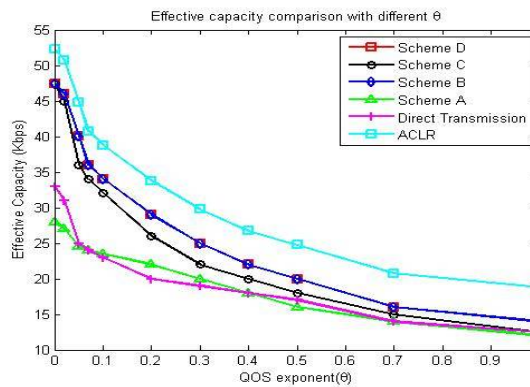


Fig:(e) Effective capacity comparison with different θ .

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VI. CONCLUSION

In this paper, we proposed resource allocation strategies in LTE-A relay network under statistical QoS constraints. It is observed that in high SINR regime, both BS and RN will distribute the power equally to all available subcarriers regardless of QoS constraints. In low SINR the QoS is more stringent and the transmit tends to spread its power over available frequency. By dual decomposition the effective capacity (EC) is maximized. When optimal power allocation strategy is introduced, the effective capacity performance is compared to that of resource allocation. The simulated result suggests that optimal resource allocation strategy achieves exactly same performance as one based on exhaustive search and the EC loss is minimum at stringent QoS constraints. The EC for OFDMA based LTE-A relay network is unknown and optimal resource allocation strategies to maximize EC are unexplored.

VII. ACKNOWLEDGEMENT

I thank my project guide Mr. Abdul Wasay Mudasser (Associate Professor), Lords Institute of Engineering and Technology for his guidance and motivation during the entire project work.

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BIOGRAPHY



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