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Adaptive Resource Allocation in Buffer Aided Wireless Network for Improving Capacity and Throughput

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Abstract- A 3-node buffer-aided relaying network with statistical Quality-of-Service (QoS) constraint in terms of maximum acceptable end-to-end queue length bound outage probability is considered. In particular, the adaptive link selection relaying problem that aims to maximize the constant supportable arrival rate μ to the source (i.e., the effective capacity) is analyzed. Fixed and adaptive source and relay power allocation are investigated for different length of packet. By employing asymptotic delay analysis, first convert the QoS constraint into minimum QoS exponent constraints at the source and relay queues. Then derive the link selection and power allocation solutions and QoS exponents using Lagrangian approach. Solutions for various special cases of link conditions, and QoS constraints are presented. Especially, Bisection search algorithm is used to find the various buffer resources. Moreover, compare the effective capacities of the proposed relaying schemes and other existing schemes under different link conditions and QoS constraints. Illustrative results indicate that the proposed schemes offer substantial performance gains, and power adaption performs fixed power allocation at low Signal-to Noise power Ratio (SNR) region or under loose QoS constraints.

Keywords:- QoS, End to End, Capacity, Performance Gain, Fixed Power Allocation, SNR.

I. INTRODUCTION

As the work on first Optimal Resource Allocation Buffer-Aided is coming to an end, the focus is now gradually shifting towards the further evolution of Optimal Resource, referred to as Buffer-Aided 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 Buffer-Aided. 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 Buffer-Aided 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 Buffer-Aided relay networks, base stations and relay nodes share the 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 delay-rate of buffer occupancy:

$$\theta = -\ \text{lim} x\rightarrow\infty \log \Pr\{L > x\} x \quad ..... (1)$$

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, consider the problem of maximizing the effective capacity of buffer-aided relay networks under channel statistics feedback. A joint subcarrier pairing and power allocation for OFDM with decodes and forward 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 buffer-aided 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-hope relay system. A multi-cell OFDMA system with decode-andforward relaying is considered. The delay sensitive mobile station is characterized by its requirement of the minimum constant data rate. However, in our paper, 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, introduce low complexity resource allocation strategies with close performance to the optimal one. These works 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.

- To characterize the effective capacity of a buffer-aided 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.
- 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.
- Identify the characteristics of the effective capacity of the buffer-aided 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.
- To decompose the original resource allocation problem into two sub-problems: subcarrier allocation and power allocation, and 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

Buffer-aided relay network is shown in Figure 1.In buffer-aided 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.

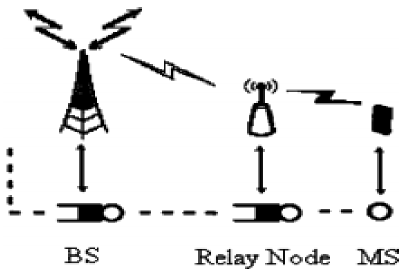

Figure 1 Communication Over Relay Node

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 buffer-aided systems, OFDMA is used for multiple accesses 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 data can sent at each time, each subcarrier of the system is assigned to either the backhaul (BSRN) link or the access link (RN-MS).

A. 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. This optimization problem is equivalent to finding the maximum of the following cost function

$$L(r,P,\mu,\lambda)=\sum_{i=1}^{2}\mu_1(\sum_{n\epsilon\Omega_g}\alpha(\theta_0,p_{tn},\beta_{tn}-r)$$
$$+\sum_{t=1}^{2}\lambda_1(p_1-\sum_{n\epsilon\Omega_1}p_{tn})+r \quad (2)$$

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

$$\frac{\partial L}{\partial P_{1n}} - \mu_1 \frac{\partial_\alpha(\theta_0,P_{1n},\beta_{1n}}{\partial P_{1n}} - \lambda_1 - 0$$
$$\frac{\partial L}{\partial P_{2n}} - \mu_2 \frac{\partial_\alpha(\theta_0,P_{2n},\beta_{2n}}{\partial P_{2n}} - \lambda_2 - 0 \quad \text{.... (3)}$$

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, and analyze 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 {γ1nP1n, γ2nP2n} _ (N0W + I), then becomes

$$\frac{\partial L}{\partial P_{1n}} = \frac{\mu_1}{P_{1n}} \frac{E[e^{-\theta_t r_{2n}}]}{E[e^{-\theta_t r_{1n}}]} - \lambda_1$$
$$\frac{\partial L}{\partial P_{2n}} = \frac{\mu_2}{P_{2n}} \frac{E[e^{-\theta_t r_{2n}}]}{E[e^{-\theta_t r_{1n}}]} - \lambda_2 \quad \text{.... (4)}$$

where rin = WT log_1 + γinPinΓ(N0W+I) for i=1,2. Set the partial derivatives to be 0 then obtain the optimal

$$P_{1n}^* = \frac{\mu_1}{\lambda_1}W, \; P_{2n}^* = \frac{\mu_2}{\lambda_2}W$$

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. In fact, the transmit power is uniformly spread over the assigned subcarriers,

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

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

$$\frac{\partial L}{\partial P_{1n}} = \frac{\mu_1}{\theta_0 T} \frac{\partial \log(1+\frac{\theta_0 WT \beta_{2n,P_{1n}}}{T(N_0W+1)})}{\partial P_{1n}} - \lambda_1$$
$$\frac{\partial L}{\partial P_{2n}} = \frac{\mu_2}{\theta_0 T} \frac{\partial \log(1+\frac{\theta_0 WT \beta_{2n,P_{2n}}}{T(N_0W+1)})}{\partial P_{2n}} - \lambda_2 \quad \text{.. (5)}$$

Let ∂L/∂P1n = 0 and ∂L/∂P2n = 0, the optimal power allocation can be expressed as

$$P^*_{1n} = \frac{1}{\theta_0 T}\left[\frac{\mu_1}{\lambda_1} - \frac{\Gamma(N_0W+I)}{W\beta_{1n}}\right]^+$$
$$P^*_{2n} = \frac{1}{\theta_0 T}\left[\frac{\mu_2}{\lambda_2} - \frac{\Gamma(N_0W+I)}{W\beta_{2n}}\right]^+ \quad \text{.... (6)}$$

where μ1, μ2, λ1 and λ2 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 x1 = μ1/λ1 and x2 = μ2/λ2. It can be seen from that the optimal power allocation strategy follows a water-filling structure where the "water levels", x1 and x2, not only depend on the total transmit powers available at the transmitters but also depend on the QoS constraint θ

$$\sum_{n\epsilon\Omega_1}\left[\frac{\mu_1}{\lambda_1} - \frac{\Gamma(N_0W+I)}{W\beta_{1n}}\right]^+ = \theta_0 \mathrm{T} P_1$$
$$\sum_{n\epsilon\Omega_2}\left[\frac{\mu_2}{\lambda_2} - \frac{\Gamma(N_0W+I)}{W\beta_{2n}}\right]^+ = \theta_0 \mathrm{T} P_2 \quad \text{..... (7)}$$

As the QoS constraint becomes more stringent, i.e., θ 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. The new methodology can introduce to solve the Lagrangian multipliers in the low SINR regime

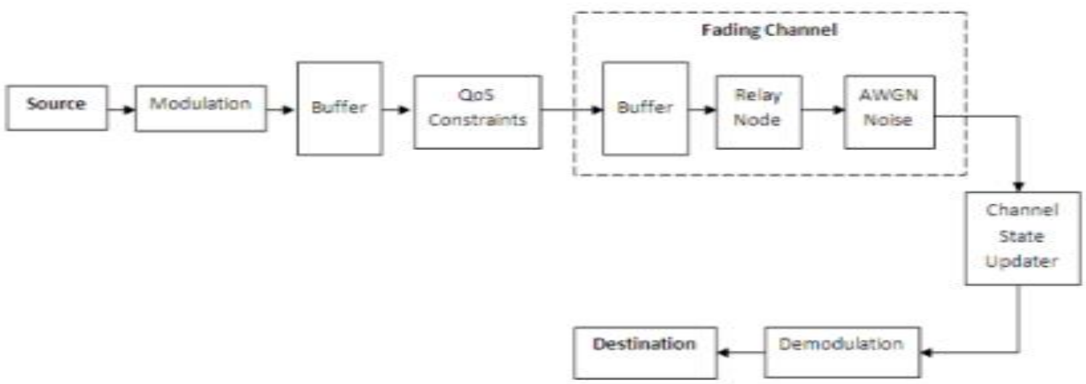

Figure 2 Buffer Aided Relaying Architecture

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, there is a need to calculate the effective capacity for each subcarrier allocation, the complexity 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. 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 show the results and simulated evaluation of a strategy for optimal resource allocation in buffer-aided advanced relay networks under statistical QoS constraints.

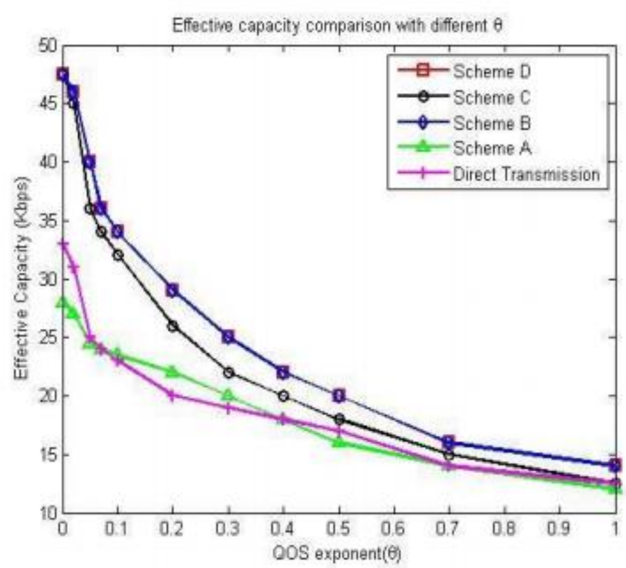

Figure 3 Effective Capacity Comparison with Different θ.

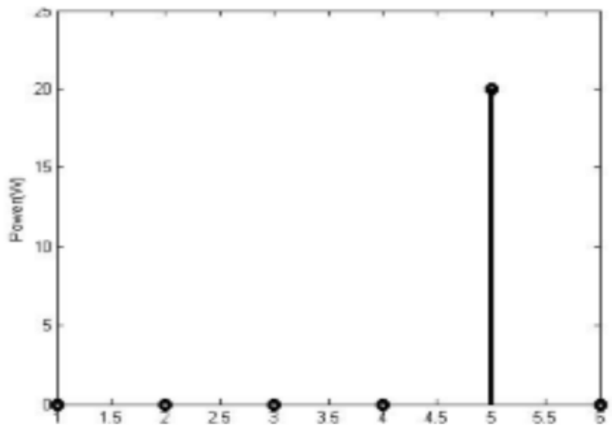

Figure 4 Power Allocation at BS when θ = 0.01.

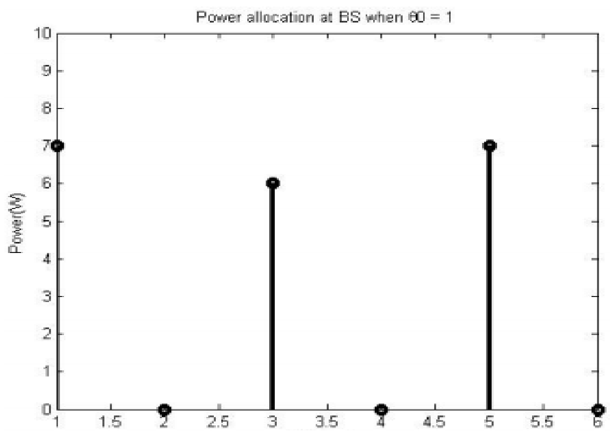

Figure 5 Power Allocation at BS when θ = 1

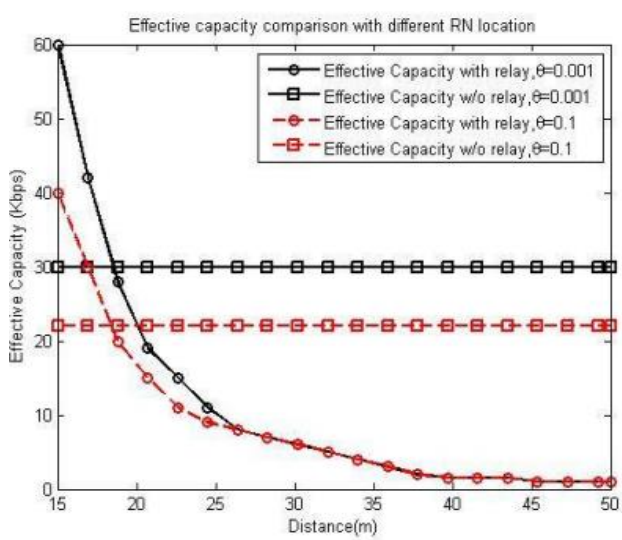

Figure 6 Effective Capacity Comparison with Different RN Location.

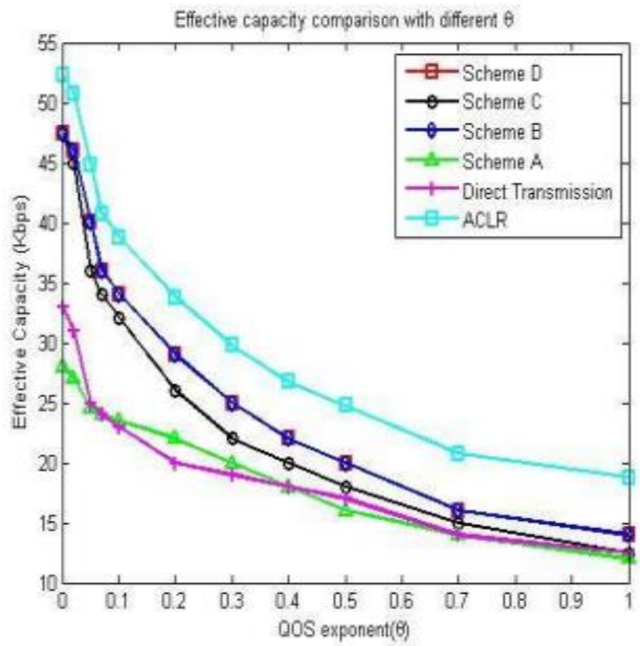

Figure 7 Effective Capacity Comparison with Different θ.

VI. CONCLUSION

In buffer-aided relaying network to exploit the relay buffering capability and link fading diversity, adaptive link selection relaying schemes with fixed and adaptive source and relay power allocation are proposed. In each transmission frame, the relay can be activated adaptively to receive packets from the source or to transmit packets to the destination depending on the instantaneous channel state information. The link selection and power allocation solutions are derived to maximize the constant supportable arrival rate μ to the source using Lagrangian approach and convex optimization. The effects of the QoS constraint on the derived solutions are identified. Illustrative results compare the capacities of the proposed relaying schemes and other existing schemes under different Signal-to Noise power Ratio (SNR) region and QoS constraints. In general, the simulation results show that buffer-aided relaying with adaptive link selection is beneficial as long as a certain delay can be tolerated.

VII. FUTURE WORK

Multiple source nodes and multiple destination nodes can be implemented. Greedy scheduling algorithm can be added to improve the throughput of the network. The advantage to using a greedy algorithm is that solutions to smaller instances of the problem can be straightforward and easy to understand.

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