QoS Aware Energy Efficient Resource Allocation in Wireless Cooperative OFDMA Relay Networks

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Abstract—In this paper, an efficient QoS aware resource allocation algorithm is proposed for wireless relay networks. This algorithm is yielded by considering G/G/1 queue for each subcarrier and using effective capacity concept to model the transmission delay in wireless relay networks. The objective is to minimize the transmission power considering support of QoS parameters. The constant user arrival rate is assumed throughout the paper. An extended Kalman filter also is used to estimate the residual times and vacation times of the relays and subcarriers. Based on the channel state information and queue state information, proposed algorithm assigns proper subcarriers to the relays. Then, the optimum subcarriers and relays are allocated for optimum power efficient transmission to the users.

I. INTRODUCTION

Real-time and high data-rate multimedia application for wireless mobile systems is growing in recent years. To satisfy this demand growth, mobile operators have to extensively enlarge their network capacity. LTE advanced as a future wireless communication testbed propose complicated techniques such as distributed MIMO, coordinated multipoint transmission (CoMP)[1] and Femtocells to enhance the capacity of wireless networks.

However cooperative communications increase the used bandwidth interfere due to the different location of the relays. Thus without precise resource management, bandwidth efficiency will decrease in a dramatic way. Therefore beside achieving high data rate, efficient bandwidth usage is also an important factor in resource allocation.

A lot of researches have been done in the way of achieving high SNR or maximizing throughput while addressing the power minimization problem through the beam-forming or optimum resource allocation [2], [4]. MIMO relay selection and resource allocation with QoS requirement also have been studied in [5].

QoS is another key point in the recent mobile user services. In [2], [4], the QoS term is referred to the adequate high SNR or buffer overflow avoidance in the cooperative wireless communications. QoS price and a dual based QoS-aware schedule (QAS) algorithm are proposed in [6] for relay selection and subcarrier allocation in a cooperative OFDMA system with considerations of QoS guarantees. The QoS requirement in [6] is just related to the minimum required transmission rate. More details about QoS requirements are provided to support real time transmission in [7], [8]. With considering different queue for each OFDMA subcarrier, a model for the end to end delay is proposed. In [9] effective bandwidth concept is used to model for QoS-delay.

In this paper, both of the ideas are used to provide a model for QoS transmission in cooperative wireless networks. Moreover, a distributed subcarrier allocation and relay selection algorithm are proposed for cooperative wireless networks. It means that per each user traffic arrival rate, the resources are optimally allocated to minimize the transmission power. The base station divides the stream into sub-streams with different power coefficients through different relays and subcarriers in the way of minimizing total transmission power. Figure 1 shows the topology of the system. The effective capacity and G/G/1 queue model have been applied for our QoS function modeling. Then, based on the number of the users and their traffic rates , the proposed algorithm tries to minimize the transmission power dedicated for each user. A suboptimal algorithm also is proposed to assign subcarriers to the relays for each scheduling period.

The rest of this paper is organized as follows: Section II presents the system model. In section III, the optimization problem considering the proposed subcarriers assignment to the relays is defined and solved. Simulation results are discussed in section IV. The paper ends by a conclusion which part IV provides to help reach the optimum QoS aware energy efficient resource allocation in wireless cooperative networks.

II. SYSTEM MODEL

$I = \{1, 2, ..., i, ..I\}$ states a collection of the relays and $J = \{1, 2, .., j, .., k\}$ states a collection of subcarriers. For each user $p_{ij}$ denotes the transmission power of the $i^{th}$ relay and $j^{th}$ subcarrier. Thus, each relay has a collection of the subcarriers for transmission. Paper parameters are defined in table I.

Throughout the paper, $E\{\}$ and $E^2\{\}$ indicate the first and second moments of the variables respectively. It is assumed that partial channel state information (first and second order of the channel gains) are available in the base station.

The approximated average queuing delay based on what has been done in [7], [8] could be written as
where \( i \) and \( j \) subscript denotes to the parameter related to \( i \)th relay and \( j \)th subcarrier. Two main delay terms are used to model each subcarrier delay: initial state delay and steady state delay. Average delay can be approximated using these two terms, where \( \Delta \) indicates the slot duration and \( \beta \) (dominant pole of queueing Laplace transform) is the variable for approximating the settling time. In fact, it is a steady state convergence time factor of channel gain. \( v \) also is considered as a time that base station and relays has to spend for the other users.

The BS service rate of the wireless link between the BS and the relay is obtained as following

\[
\mu_{sij} = \omega_j \log_2(1 + \frac{p_{sij}h_{sr(ij)}}{\Gamma_{ij}\sigma^2_{sr(ij)}}) \tag{2}
\]

The \( i \)th relay service rate could be calculated by

\[
\mu_{rij} = \omega_j \log_2(1 + \frac{p_{rij}h_{rij}}{\Gamma_{ij}\sigma^2_{n(ij)}}) \tag{3}
\]

where

\[
\Gamma_{ij} = -\ln(BER_{ij}) \tag{4}
\]

In order to minimize the total transmission power, the total arrival rate of the user \((\lambda)\) has to divide into sub-rates \(\lambda_{ij}\).

### A. Subcarrier Allocation Algorithm

In order to minimize the signal to interference ratio, it is assumed that each relay and base station has to transmit in a same subcarrier for specific user [10]. Optimum subcarrier allocation algorithm has to minimize the delay of transmission while maximizing the achievable transmission rate. Therefore optimal solution is corresponded to the following multi-object optimization problem:

\[
\begin{align*}
\max_x (\text{min}(h_{sxj}, h_{rxj})) & \\
\min_x(R_i + B_i/\mu_{xj}) & \\
\forall x \in I \ | D_{\text{init}}(x) \geq D_{\text{init}(i)} \rightarrow j \in SC_i & \\
D_{\text{init}}(x) &= R_x + \min_x(p_{sxj|xjx} = p_{sxj} | p_{rxj} = P_i) \tag{5}
\end{align*}
\]

However, the mentioned algorithm output gives just subcarrier candidates for relay selection and power allocation algorithm. Then, Through Water-Filling algorithm, The nonzero subcarriers power coefficients could be found both for the BS-relay and relay-user schemes. In other word

\[
\{\forall i, j \in SC_{im} | \Delta_s - \frac{\eta_j}{h_{sxj}}, \Lambda_r - \frac{\eta_j}{h_{rxj}} > 0\} \tag{7}
\]

From now to the end of the paper, it is assumed that relays per subcarrier for each user are known through using 7. In the rest of the paper \( i \) subscript will be neglected for notation simplicity.

In this section, subcarriers to relays are assigned based on the initial delay and service rate(higher channel gain), then using Water-Filling, relays subcarriers for the \( m \)th user transmission are selected. These subcarriers are just candidates which has to be qualified in the next section. Final decision for subcarrier selection will be discussed in the following section.

### III. Resource Allocation

Effective capacity concept is a very well-known and popular in the statistical QoS theory of wireless systems. In [6] effective capacity concept has been used to model downlink wireless link delay. With assuming that arrival rates and service rates of the wireless links are all stationary and independent, Based on Gartner-Ellis Limits [11],[12],If D, Dth

![Fig. 1. Topology](image-url)
represent end to end delay and end to end delay threshold \( \text{pr}(D > D_{th}) = \delta \). Wireless link delay violation probability could be approximated by [13]

\[
\text{pr}(D_{srj} > D_{th-srj}) \approx e^{-\varphi_{srj} \lambda, D_{th-srj}}
\]

(8)

where

\[
\varphi_{srj} = \frac{-\ln \delta}{\lambda_j, D_{th-srj}}.
\]

As it defined in section II, total transmission delay threshold could be obtained by the sum of the BS-relay threshold and Relay-User Delay threshold as follows

\[
D_{th-srj} + D_{th-rj} = D_{th}
\]

(9)

From [11, 12, 13] QoS aware transmission should satisfy

\[
E_{h_{srj}} \{e^{-\varphi_{srj} \lambda_j} - e^{-\varphi_{srj} \mu_{srj}}\} > 0
\]

(10)

Therefore, Transmission power optimization problem can be written as:

\[
\begin{align*}
\text{Arg min}_{\lambda, \mu_p, \mu_r} & \sum p_{sj} + p_{rj} \\
\text{S.T} : & D_{th-srj} + D_{th-rj} < D_{th} \\
& E_{h_{srj}} \{e^{-\varphi_{srj} \lambda_j} - e^{-\varphi_{srj} \mu_{srj}}\} > 0 \\
& D_{rj} \leq D_{th-rj} \\
& \lambda_j, \mu_p, \mu_r \geq 0 \\
& E_{h_{srj}, h_{rj}} \{SNR_j\} > SNR_{th} \\
& D_{th-srj}, D_{th-rj} > 0
\end{align*}
\]

From [4] SNR of the user in the case of amplify and forward relaying is equal to

\[
SNR_j = \frac{p_{sj} p_{rj} h_{srj}^2 h_{rj}^2}{\sigma^2 (1 + p_{rj} h_{rj}^2)}
\]

(11)

Similar to what has been done in [7, 8] using KKT condition, \( \lambda_j \) coefficients could be obtained through using

\[
\lambda_j = \mu_{sj}(1 - \sqrt{A_1 \sigma^2_{srj}})_+
\]

(12)

where \( A_1 \) is an Lagrangian coefficient obtained by

\[
\sum_{j=1}^{n} \lambda_j = \lambda
\]

From [8], \( \lambda_j \) has to be in the form of:

\[
\lambda_j = \mu_{sj}(1 - k_j)_+
\]

(13)

Therefore, \( k_j \) can be easily obtained as follows

\[
[k_j = 1 - \frac{\mu_{rj}}{\mu_{sj}}(1 - \sqrt{A_1 \sigma^2_{srj}})]
\]

(14)

Therefore, to find the optimum power coefficients, we divide the problem into two optimization problems: Relay subcarriers power transmission coefficients and Base Station subcarrier power transmission coefficients, in each case we substitute \( \lambda_j \) in terms of relays and BS transmission power coefficients. Using KKT condition on new optimization problems leads to

\[
p_{rj} = \frac{[\Lambda_{pr-1}(1 - \sqrt{A_1 \sigma^2_{srj}}) + \Lambda_{pr-2}(1 - \frac{1}{\sqrt{A_1 \sigma^2_{srj}}}) - \frac{\eta_{sj}}{h_{rj}}]}{\Lambda_{ps-1} + \Lambda_{ps-2}(1 - k_j) - \frac{\eta_{sj}}{h_{rj}}} + \lambda
\]

\[
p_{sj} = \frac{[\Lambda_{ps-1}(1 - \sqrt{A_1 \sigma^2_{srj}}) + \Lambda_{ps-2}(1 - \frac{1}{\sqrt{A_1 \sigma^2_{srj}}}) - \frac{\eta_{sj}}{h_{rj}}]}{\Lambda_{pr-1} + \Lambda_{pr-2}(1 - k_j) - \frac{\eta_{sj}}{h_{rj}}} + \lambda
\]

where \( \Lambda_{pr-1}, \Lambda_{ps-1} \) are Lagrangian coefficients could be obtained by solving \( \sum_{j=1}^{n} \mu_{rj}(1 - \sqrt{A_1 \sigma^2_{srj}})_+ = \lambda \), \( \sum_{j=1}^{n} \mu_{sj}(1 - k_j) = \lambda \) respectively. \( \Lambda_{pr-2}, \Lambda_{ps-2} \) also could be calculated by solving \( D_{rj} = D_{rj-th} \) in terms of \( \mu_{sj}, \mu_{rj} \).

Due to the variables dependency, It is necessary to update the solution in a heuristic way after finding the closed form optimum coefficients. As it mentioned before it is assumed that large scale fading and path loss parameters of the channel do not vary during the time slot. The relay buffers, residual and vacation times of the relays are estimated through using an extended Kalman filter [14].

\[
x_{n+1} = A_n x_n + B_n u_n + e_n
\]

where \( u \) subscript shows the time slot number, \( X(R, V) \) is a \( 1 \times 21J \) vector represents state variable related to all residual and vacation times of all relays in different subcarriers. \( u \) is considered as a simple vector of the network inputs. It consists of \( \lambda(M) \) (users arrival rates vector) and \( H \) (channels gains vectors). \( y_n \) denotes to \( R_n, V_n \) (residual and vacation times of the subcarriers and Relays) In this paper, \( F_n, L_n, h(x) \) matrices is calculated through using Lyapanov drift optimization method [15]. \( e_n = y(n) - h(x(n)) \) is also considered as a Gaussian estimation error with zero mean. The Kalman filter parameters \( (P_n, K_n) \) based on [16] could be obtained by:

\[
P_{n+1} = A_n P_n A_n^T - K_n C_n P_n C_n^T Q_n + Q_n K_n^T
\]

\[
K_{n+1} = A_n P_n C_n^T (C_n P_n C_n^T + Q_n)^{-1}
\]

where \( Q_n \) denotes to the error covariance matrix and:

\[
A_n = \frac{dF_n}{dx_n}, C_n = \frac{dh_n}{dx_n}
\]

IV. NUMERICAL RESULTS

In this section, we evaluate the performance of our proposed algorithm. We consider 128 subcarriers with 1 Mhz bandwidth and 5 relays. The channel gains are assumed independently identically distributed between \((0,1)\). The arrival traffic of the users are considered as a Gaussian process with mean of 1mbps and variance of the 200 kbps. The buffer size of each relay is considered 50 MB. Packet size is equal to 1kb. Received packets with more than 2 percent error are dropped. The proposed algorithm performance is compared with random relay selection and QAS [6]. Number of drop packets for a user flow has been compared in figure2. The proposed
algorithm using decode and forward (DF) relaying has the least buffer overflow rate, transmission error rate and threshold delay violation rate. The number of drop packets per second has been shown in figure 2. The proposed algorithm using AF also has a good performance in comparison with other algorithms.

Figure 3 compares energy efficiency of different schemes. As it is shown in figure 3, for all different users in the cell the proposed algorithm has a better energy efficiency.

In figure 4, average packet loss of users with different range of the total transmission power are compared. The proposed algorithm with DF relaying has the least transmission power in comparison with other transmissions schemes.

V. CONCLUSION

In this paper, an optimum power efficient resource allocation algorithm is proposed for wireless relay OFDMA networks. Different buffer for each subcarrier is considered. Then for a constant arrival rate, the total transmission power is minimized. In first step, the subcarriers are assigned to the relays for each flow. In the second step, relays and subcarriers are selected for the connection with power allocation over the relays and base station. Numerical results show our proposed algorithm in comparison with other algorithm, saves more energy of the transmission while satisfying QoS constraints.

REFERENCES