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Resource Allocation for OFDMA MIMO Networks with Network Coding at Relay Station

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Abstract: In wireless cellular network, subchannel and power allocation are the two major technical challenges due to growing wireless multimedia access. To improve the coverage of high data rates and to extend coverage to dead spots in the areas beyond the cell range, relay nodes are introduced. In this paper, an opportunistic resource scheduling problem is solved for the OFDMA based mobile relay enhanced cellular network. To minimize the number of transmissions and to minimize the power consumption, network coding technique is performed at each fixed relay and mobile relay. The flexible resource allocation is achieved by dynamic Time Division Duplexing technique, where each time slot is divided into four phases according to the type of transmission nodes such as base station, mobile station, fixed and mobile relay. An opportunistic resource scheduling algorithm is proposed to jointly allocate the subchannel and transmission power based on channel state of each wireless link. The overall network throughput can be improved by performing dynamic network coding at each fixed and mobile relay. Simulation results show that the proposed opportunistic scheduling algorithm along with the network coding technique improves the spectral efficiency and enhance the coverage area.

Keywords: OFDMA, resource allocation, network coding, sumrate, optimization, fixed relay, mobile relay.

I. INTRODUCTION

The key expectation for the next generation wireless network is to provide high data rate, increasing the coverage area and meet the users demand. To achieve this objective Orthogonal Frequency Division Multiplexing Access (OFDMA) and relaying technique is used. In a relay enhanced cellular network, multiple mobile relays are deployed to assist transmission between base station and multiple mobile stations. The introduction of mobile relay based communication network enjoys advantages over coverage efficiency, operation cost and transmission capacity. In relay enhanced cellular network link capacity and coverage is mainly dependent on the resource allocation strategy. OFDMA based relaying technique have challenges to allocate the resources because of the increased number of users and increased number of links.

The resource allocation problem in OFDMA consists of multiple independent problems:

1). Subcarrier assignment

2). Choice of modulation levels

3). Rate and fairness constraints

Network coding is one of the promising techniques to increase network throughput, efficiency, scalability. In wireless networks, many researchers have shown that network coding scheme improve network performance [6], [10]. COPE is a new forwarding architecture that cans XOR more than a pair of packets and it is transmitted using single transmission to destined node that leads to larger bandwidth savings [10]. Zhang and Li studied [7], with network coding it becomes possible to assign same set of subcarriers to different downlinks without causing any interference. The performance of XOR operation in the relay station to encode packets can reduce traffic load in a relay station so that a number of orthogonal subcarriers can be saved for other applications [4]. Several recent works [2], [4], [5], [8] used multi carrier system OFDMA in which the frequency band is split into multiple independent resource blocks that can be modeled as non-interfering flat narrowband channels. The integration of multihop relaying with OFDMA system has become one of the most promising solution for next generation wireless cellular network. In OFDMA each subcarrier can be allocated to a different user which can best exploit the current channel condition hence maximizing the achievable capacity [2]. In order to ubiquitous high data rate coverage, mobile relaying is an effective method to further improve the throughput of cell edge users. Mobile relay assisted OFDMA networks are considered as a good candidate in future deployment scenarios for coverage extension and lower deployment costs are promising solutions for provision of ubiquitous high data rate services in wide coverage areas. To implement OFDMA based mobile relay enhanced cellular network, resource allocation is a critical issue for service providers. Several papers used resource allocation algorithms such as Coding Aware Dynamic Subcarrier assignment algorithm, opportunistic resource scheduling algorithm, dynamic subcarrier assignment algorithm [2], [7], [8] to solve the resource allocation problem. Recently opportunistic scheduling is a promising technique to improve system efficiency in wireless systems [2], [3], [5].

In this paper to enhance data rate and coverage area mobile relays are introduced for cellular network. An opportunistic resource scheduling algorithm is designed for the OFDMA based mobile relay and fixed relay enhanced cellular network with network coding at each mobile relay, which includes joint subchannel and transmission power scheduling, sum rate maximization. Two-hop transmission is achieved by considering the dynamic Time Division Duplexing technique where each time slot is divided into four phases: the first phase is allocated for the transmission of base station, second phase is allocated for the transmission of mobile station, third phase is allocated for the transmission of fixed relay and fourth phase is allocated for the mobile relay. Designed resource scheduling algorithm is available in base station and is responsible for allocating the subchannel and transmission power based on time varying channel states of wireless link which is periodically updated from fixed relay stations, mobile relay and mobile station. An optimal opportunistic resource scheduling algorithm fully utilizes two techniques:

1). Network coding

2). Dynamic Time Division Duplexing

Communication networks are designed to deliver information from source to destination nodes. Network coding is a networking technique which performs XOR operation that allows each node or router in the network to encode the data received from multiple links and forwards the mixed one to its neighboring nodes. Such a processing mode will reduce the information congestion at some nodes or links and improve the network information flow. When network coding is performed only fewer transmissions are required to transmit all data.

When mobile station and base station wants to exchange the information through relay station network coding is performed at relay station. In traditional routing network's four transmissions are needed to exchange the information through relay station. When network coding is performed at relay station it reduces the number of transmission from four to three. Thereby saving the transmission power, bandwidth, and network gain is improved.

The remainder of this paper is organized as follows. The system model is presented in Section II. In Section III, we formulate an optimization problem and develop an opportunistic resource scheduling algorithm that solves the problem. We provide numerical results in Section IV, and the conclusion is followed in Section V.

II. System Model

Consider a single cell OFDMA based wireless cellular network with single base station, communicating with M mobile users and assisted by R mobile relay nodes, as shown in figure 1. Each of the users is assigned an orthogonal subchannel, over which the base station to user and the relay to user communications takes place.

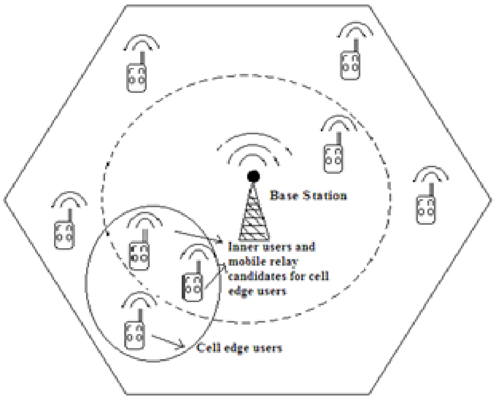

Fig.1. OFDMA based mobile relay enhanced cellular network

A. TIME SLOT STRUCTURE

Consider a Time Division Duplexing system where each timeslot is divided into three phases as shown in figure 2. The communication between the base station and a user happens over four phases in each timeslot. In the first phase, the base station is allowed to transmit to mobile station, fixed relay and mobile relay, in the second phase, the mobile station is allowed to transmit to base station, fixed relay and mobile relay, in the third phase fixed relay is allowed to transmit to base station and mobile station and network coding is performed and in the fourth phase, the mobile relay is allowed to transmit to base station and mobile station. The index for three phases are denoted as $\rho \in \{1,2,3,4\}$. Time duration for each phase in a timeslot is denoted as t_ρ^s, where t_1^s denotes time duration for phase 1, t_2^s denotes time duration for phase 2, t_3^s denotes time duration for phase 3 and t_4^s denotes time duration for phase 4.

The wireless link between two nodes are denoted as (i,j), where i denotes the transmitting node and j denotes the receiving node. Set of all wireless links to which subchannels can be allocated at each ρ^{th} phase is denoted as W_ρ.

$$W1 = \{(0,j)|\ j \in M \cup R\} \quad (1)$$

$$W2 = \{(i,j)|\ i \in M, j \in R \cup \{0\}\} \quad (2)$$

$$W3 = \{(i,j)| i \in FR, j \in M \cup \{0\}\} \quad (3)$$

$$W4 = \{(i,j)| i \in MR, j \in M \cup \{0\}\} \quad (4)$$

Where index 0 represents the base station

TIMESLOT

PHASE 1	PHASE 2	PHASE 3	PHASE 4
BS to MS	MS to BS	FR to BS	MR to BS
BS to FR	MS to FR	FR to MS	MR to MS
BS to MR	MS to MR		
		NETWORK CODING	NETWORK CODING

TIME DOMAIN

Fig. 2: Timeslot structure for the mobile relay enhanced cellular network

B. CHANNEL MODEL

The channel state of each wireless link on each subchannel is modeled as a stationary stochastic process and also the channel state of a wireless link to be time varying and frequency-selective. The channel between the base station and relay j is denoted as h_{brj}. Similarly h_{riMj} is the channel between relay i and mobile station j. The total frequency band is divided into N orthogonal subchannels each of which consists of number of subsequent subcarriers. The whole system state is defined as the combination of the current channel state of all wireless links on all subchannels in the system. Assume that at the beginning of each timeslot, the current channel state of all wireless links in the cell is delivered from mobile stations, fixed relay stations and mobile relays to the base stations. Hence at the beginning of each timeslot, the resource scheduling algorithm can takes place at the base station. At each mobile relay and fixed relay station a buffer is maintained which can be used for storing the received data from base station or mobile stations and the resource scheduling and the network coding strategy can be adjusted based on the current channel states of its outgoing links.

C. MODEL FOR NETWORK CODING

Assume that all relay nodes are able to perform XOR network coding operation. Consider base station and mobile station wants to exchange the information via mobile relay or fixed relay station and assume that the base station and all mobile station store the data which they already transmitted to relay station for two hop communications within their own buffer for some time. Hence when fixed and mobile relay performs XOR network coding operation with downlink and uplink sessions of a mobile station, the corresponding mobile station and the base station can decode the received coded data with the help of already stored data within their own buffer. In most of previous works on the subchannel allocation problem for OFDMA systems without network coding, each subchannel is restricted to be assigned to at most one wireless link. But when network coding technique is performed, the encoded data can be forwarded to multiple nodes in a single transmission.

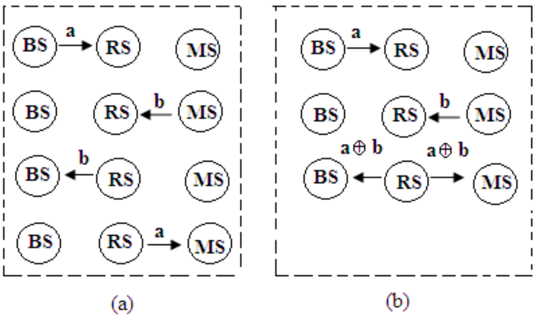

Figure 3: Reducing number of transmission and power consumption (a) Traditional approach (b) Network coding approach

For example, consider relay station i wants to forward the coded data with the downlink sessions and uplink sessions of mobile station j, it should be able to transmit it through two wireless links i.e, relay station to base station link (i,0) and relay station to mobile station link (i,j), simultaneously on the same subchannel. To effectively model such multicast transmission of the coded data, a virtual node is created for each mobile station. The virtual node of each fixed relay and mobile relay station j is denoted as f(j) and m(j). The set of virtual node is defined as,

$$V = \{f(j)\&m(j) | j \in M\} \quad (5)$$

In order to transmit the coded data from relay station at the third phase, a virtual link is created between each relay station and each virtual node. Set of virtual link is defined as,

$$D = \{(i, f(j)\&m(j)) | i \in MR, j \in M\} \quad (6)$$

Assume that if subchannel n is assigned to virtual link (i, f(j)&m(j)) at the third phase which indicates that XOR network coded data with the downlink and uplink sessions of mobile station j is multicast to both the base station and mobile station j from relay station i through that subchannel. When relay station transmits a coded data to both the base station and the mobile station, in order to successfully decode the coded data at both nodes, the relay station transmission data rate should be smaller than or equal to the minimum between the achievable instantaneous data rates of the corresponding relay station to base station link and relay station to mobile station link. Hence the channel gain of virtual link (i, f(j)&m(j)|) be the minimum between channel gains of relay station to mobile station link and relay station to mobile station link.

$$a(i, v(j)) = \min(a(i, j), a(i, 0)) \quad (7)$$

where i denotes the relay station, j denotes the mobile station and 0 denotes the base station. Assume that if group of subcarriers i.e, subchannel is assigned to particular user it will be indicated as $S^{n,s}(i,j)$.

$S^{n,s}(i,j) = 1$; if subchannel n is assigned to link (i,j) in a timeslot with system state S

$S^{n,s}(i,j) = 0$; otherwise

At the third phase based on the subchannel assignment to virtual links, have to determine whether or not to perform network coding and which mobile stations are encoded together, that performance allowing opportunistic network coding. The transmission power for link (i,j) on subchannel n in a timeslot with system state S is denoted as $P^{n,s}(i,j)$. The overall power allocation for all links in a timeslot with system state S is represented as,

$$\overline{p_S} = [P^{n,s}(i,j)] \quad (8)$$

The maximum transmission power limit for each subchannel is represented as,

$$P_s = \{\overline{p_S} | 0 \le P^{n,s}(i,j) \le P_{max}\} \quad (9)$$

The constraint on average transmission power for base station, mobile station, fixed and mobile relay is represented as,

$$\sum_{j\in R\cup M} \sum_{n\in N} P^{n,s}(0,j) = P_i \; ; \; i \in B \quad (10)$$
$$\sum_{j\in R\cup\{0\}} \sum_{n\in N} P^{n,s}(i,j) = P_i \; ; \; i \in M \quad (11)$$
$$\sum_{j\in M\cup\{0\}} \sum_{n\in N} P^{n,s}(i,j) = P_i \; ; \; i \in FR \quad (12)$$
$$\sum_{j\in M\cup\{0\}} \sum_{n\in N} P^{n,s}(i,j) = P_i \; ; \; i \in MR \quad (13)$$

Where P_0 denotes maximum transmission power for base station, P_i denotes maximum transmission power for mobile station, fixed relay and mobile relay in the corresponding phases. The achievable instantaneous data rate of link (i,j) on subchannel n is defined using Shannon's channel capacity as

$$r^{n,s}(i,j) = \log_2(1+a^{n,s}(i,j)P^{n,s}(i,j)) \quad (14)$$

where $a^{n,s}(i,j)$ indicates the channel gain for link (i,j) on subchannel n in a timeslot with system state S.

When two hop transmission via relay station is preferred, in order to forward all the received data which are stored at corresponding relay station buffer, its average achievable transmission rate must be higher than or equal to its receiving rate. To achieve this, two constraints are defined for each relay station each of which corresponds to each of uplink and downlink transmissions through relay station:

$$\text{DOWNLINK} : \sum_{j\in M} R^s(i,j) = R^s(0,i) \quad (15)$$
$$\text{UPLINK} : R^s(i,0) = \sum_{j\in M} R^s(j,i)$$

In equation (7) and (8), the left hand side indicates the average transmission rate of relay station i and the right hand side represents the average receiving rate of relay station i.

The main objective is to maximize the weighted sum rate for both uplink and downlink sessions of all mobile stations which is defined as,

$$\max \sum_{i\in R\cup\{0\}} \sum_{j\in M} \left(W_j^{DL} R^s(i,j) + W_j^{UL} R^s(j,i)\right) \quad (16)$$

III. THE PROPOSED OPPORTUNISTIC RESOURCE SCHEDULING FOR MOBILE RELAY ENHANCED CELLULAR NETWORKS

The algorithm proceeds by the details given below:

- Initialize timeslot T=0

- For each phase $\rho \in \{1,2,3,4\}$ in each timeslot, base station allocates subchannel and transmission power based on channel states which is periodically updated from corresponding mobile station and relay station

Subchannel allocation:

$$S^{n,s}(i,j) = \begin{cases} 1 & \text{if } (i,j) = \text{argmax}\left(\lambda(i,j) * \log_2\left(1 + a^{n,s}(i,j)p^{n,s}(i,j)\right)\right) \\ 0 & \text{otherwise} \end{cases} \quad (17)$$

Power allocation:

$$p^{n,s}(i,j) = \begin{cases} \text{argmax}(\lambda(i,j) * \log_2(1 + a(i,j) * p) - v_i p) & \text{if } S^{n,s}(i,j) \\ 0 & \text{otherwise} \end{cases} \quad (18)$$

- Based on achievable total data rate in each phases base station adjusts the duration of each phase.
- Increament the timeslot T=T+1
- Repeat the steps for each timeslot T.

IV. RESULTS AND DISCUSSION

In this section, simulation results are analyzed for the proposed resource scheduling algorithm. For the simulation, a single cell of an OFDMA based mobile relay enhanced cellular network is considered in which 12 mobile users are uniformly distributed around the base station. The total frequency bandwidth is set to B = 20 MHz which is divided into 35 subchannels with equal bandwidth. Assume the maximum transmission power of the base station, mobile station, and relay station are set to be 10W, 3W, and 1W.

In figure (4), (5), (6), (7) and, (8), the performance of the proposed opportunistic resource scheduling algorithm is analyzed. Cellular network is analyzed with three kinds of network coding: dynamic network coding, static network coding, and without network coding. Dynamic network coding was performed at each relay station. Such kind of coding checks whether the nodes having the data which is intended for same destination. Based on that condition, network coding is performed at each relay station. Hence the sum rate was increased for increasing distance compared to static network coding and without network coding. Figure (7) shows that the proposed resource scheduling algorithm for mobile relay has the high end to end throughput compared to fixed relay station.

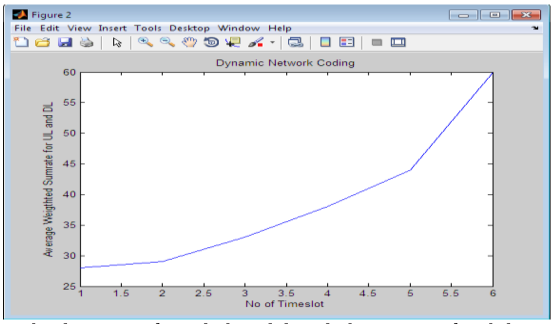

Fig 4: No.of.timeslot VS Average weighted sum rate for uplink and downlink sessions of mobile stations with dynamic network coding

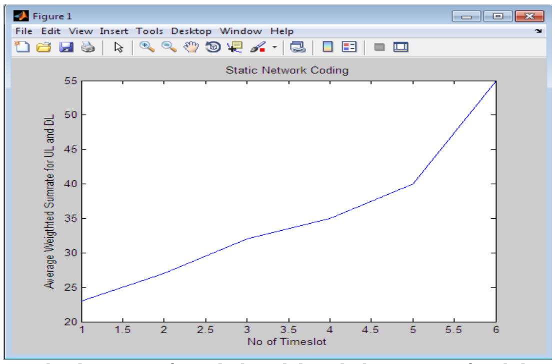

Fig 5: No.of.timeslot VS Average weighted sum rate for uplink and downlink sessions of mobile stations with static network coding

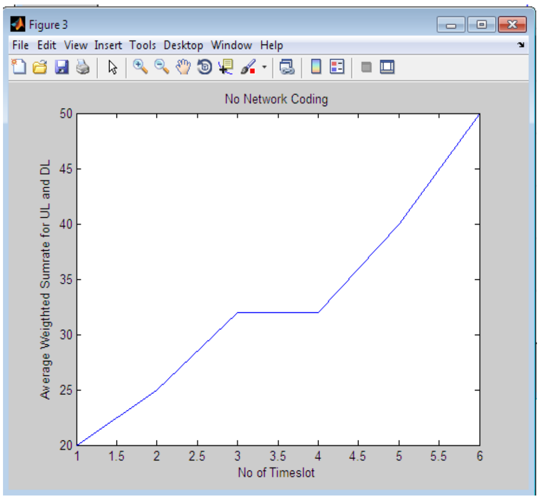

Fig 6: No.of.timeslot VS Average weighted sum rate for uplink and downlink sessions of mobile stations without network coding

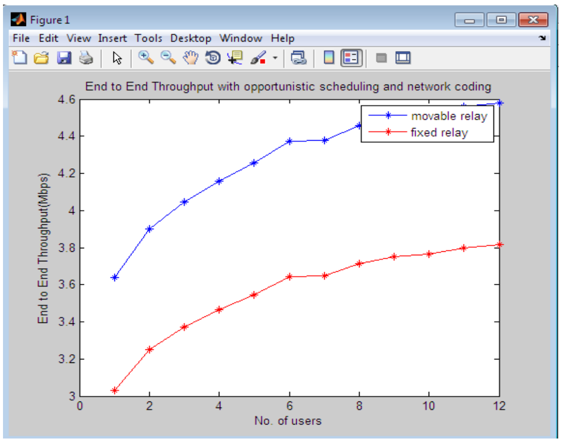

Fig 7: No.of.Users VS End to End throughput

V. CONCLUSION

In this paper, resource scheduling problem is solved for mobile relay enhanced cellular network with network coding at mobile relay nodes. The overall network throughput is improved by performing opportunistic network coding at each mobile relay. Thus the simulation results shows that the efficient utilization of available bandwidth, transmission power and with network coding at relay nodes improves the spectral efficiency and overall network throughput.

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