MIMO Link Adaptation with Carrier Aggregation in LTE-A Heterogeneous Networks

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***Abstract*—In this work, we present an enhanced MIMO LA algorithm, which facilitates the improvement of the total throughput when CA is employed in HetNets. In particular, the performance of the LTE-A physical downlink channel is assessed in terms of throughput, assuming that the proposed algorithm is utilized in a closed-loop spatial multiplexing MIMO wireless system under non-continuous heterogeneous CA.**

***Index Terms*—Carrier Aggregation, Heterogeneous Networks, Long Term Evolution-Advanced.**

I. Introduction

LTE-A HetNets deployment with CA technology was initially introduced in [1]. Although LTE-A supports various MIMO techniques and also advantageous LA algorithms, to the best of the authors' knowledge, HetNets employing MIMO LA with CA have not been studied yet. In this work, we study the implementation of LTE-A evolving physical layer technologies in HetNets, which involve pico- and macro-eNode basestations (eNodeBs). We consider a practical LTE-A scenario under non-contiguous (NC) CA with closed-loop spatial multiplexing (CLSM) MIMO LA. The contributions of this paper can be summarized as follows:

- A performance analysis of how the current MIMO LA techniques affect the behavior of CA per CC in HetNets (i.e., performance assessment at the transmitter and/or receiver), is conducted in terms of throughput.
- An improved MIMO LA algorithm, which facilitates the enhancement of the total throughput is also presented.
- The impact of different LTE-A fading channel models and outdated feedback on the performance of the proposed LA algorithm is demonstrated.

II. System Model

We consider a practical LTE-A scenario with NC CA in a HetNet considering CLSM MIMO LA. In CLSM, the UE analyzes the current channel conditions and provides a set of RIs and PMIs for each eNodeB. Each eNodeB may decide its transmission rank, $L_j, j \in \{1, 2\}$, taking into account the RI reported by the UE, as well as other factors, such as the traffic pattern, the available transmission power, e.t.c. We assume that the CLSM used by macro eNodeB consists of L_1 layers and $N_T^{(1)}$ transmit antennas ($N_T^{(1)} \geq L_1$), while the one used by pico eNodeB consists of L_2 layers and $N_T^{(2)}$ transmit antennas

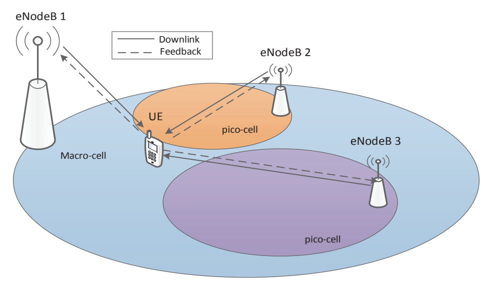

Fig. 1. System model and UE architecture.

($N_T^{(2)} \geq L_2$). To support adaptive modulation and coding (AMC) in the downlink, the UE needs to feed back a set of CQI values at each eNodeB.

We assume three delay profiles namely Extended Pedestrian A model (EPA), Extended Vehicular A model (EVA) and Extended Typical Urban model (ETU), corresponding to a low, medium and high delay spread, respectively. The maximum Doppler frequency utilized for each profile is specified as 5 Hz for the EPA, 5 or 70 Hz for the EVA and 70 or 300 Hz for the ETU by 3GPP [3]. The received wideband RF signal, which consists of two CCs with bandwidth W_1 and W_2 and center frequencies f_1 and f_2, respectively, is passed through various RF front-end stages including filtering, amplification, analog-to-baseband down-conversion and sampling, as shown in Fig. 1.

III. Feedback and Link Adaptation Algorithm

A. Quality Metrics and Feedback Parameters

The feedback strategy is based on averaging the post-equalization SNR of each CC ($SNR^{(j)}$) over all resources of interest. Effective SNR mapping (ESM) method maps several SNR values to an effective SNR value of an equivalent SISO additive white Gaussian noise (AWGN) channel that is given by [5]

$$SNR_{eff}^{(j)} = \beta f^{-1}\left(\frac{1}{R}\sum_{r=1}^{R}\frac{SNR_r^{(j)}}{\beta}\right), \quad (1)$$

where R corresponds to the number of resources of interest, $f(x) = \exp(x)$ and β is a scale parameter, which depends of the modulation and coding scheme.

1) PMI and RI Feedback: The PMI and RI values indicate the precoder that maximizes the mutual information for a specific subcarrier $k_j \in \{1, \ldots, K_j\}$ of CC $j \in \{1, 2\}$ and temporal-range $n_j \in \{1, \ldots, N_j\}$ of interest. Denoting $I_{j,k,n}$ the mutual information of the resource element (j, k, n) we obtain:

$$\mathbf{W_m}^{(j)} = \arg \max_{\mathbf{W_i^{(j)}} \in \mathcal{W}_l} \sum_{k=1}^{K} \sum_{n=1}^{N} I_{j,k,n} \left(\mathbf{W}_i^{(j)} \right), \tag{2}$$

where the mutual information is given in terms of the post-equalization $SNR_{j,k,n,l}$ as

$$I_{j,k,n} = \sum_{l=1}^{L_j} \log_2 \left(1 + SNR_{j,k,n,l} \right), \tag{3}$$

in bits per channel use, with L_j denoting the number of spatial transmission layers. The post-equalization SNR on layer l equals

$$SNR_{j,k,n,l} = \frac{\left| \mathbf{K_{k,j,n}} \left(l, l \right) \right|^2}{\sum_{i \neq l} \left| \mathbf{K_{k,j,n}} \left(l, i \right) \right|^2 + \sigma_n^2 \sum_i \mathbf{F_{k,j,n}} \left(l, i \right)}, \tag{4}$$

where $\mathbf{K}_{k,j,n} \left(l, i \right)$ refers to the element in the $l-$th row and $i-$th column of the matrix $\mathbf{K_{k,j,n}}$.

The basic idea of the proposed LA algorithm is to maximize the throughput of each CC, so that the system will be able to achieve the maximum possible data rate. The complete LA per CC algorithm is presented below and comprises the following steps:

1) The post-equalization SNRs and mutual informations for all rank and precoding matrix combinations and all RBs of each CC are computed using (4) and (3), respectively.
2) The rank and precoding matrix combination that maximizes the total mutual information over all RBs for each CC are selected, as described in (2). Note, that the RI is given by this layer number and the PMIs by the codebook indices of the precoders. Furthermore, a layer number L can only be combined with the corresponding precoders from $\mathcal{W}_{\mathcal{L}}$, which is given by [3, Table 6.3.4.2.3-1] for transmission of 2 antennas, and by [3, Table 6.3.4.2.3-2] for transmission on 4 antennas.
3) The effective SNRs, using ESM (see Eq.(1)), are calculated for each CC and are mapped to the corresponding CQI values.

Next, each CQI, PMI and RI sequences are fed back to the corresponding eNodeB by error free feedback channels.

Algorithm 1 Component Carrier Link Adaptation Algorithm

```
function SNRcalc(j, k, n, l)
    return SNR_{j,k,n,l}
end function
function Icalc(k, n)
    return I_{k,n}
end function
function Wcalc(j)
    return W_m^{(j)}
end function
function SNReffcalc(j)
    return SNR_eff
end function
J ← 2 Component Carriers
K = {K_0, K_1} ← Number of subcarriers of each CC
N = {N_0, N_1} ← Number of RB carried by each CC
L = min(N_T, N_R) ←
Maximum number of transmission layers of each CC
SNR[J][K][N][L] SNR per possible precoding matrix
I[J][K][N][L] Mutual information
W_m[J] Precoding matrix
j, k, n, l ← 0
while j < J do
    while k < K_j do
        while n < N_j do
            while l < L do
                SNR_{j,k,n,l} ← SNRcalc(j, k, n, l)
                l ← l + 1
            end while
            I_{j,k,n} ← Icalc(k, n)
            n ← n + 1
        end while
        k ← k + 1
    end while
    SNR_eff[j] ← SNReffcalc(j)
    l_optimal[j], m_optimal[j] ← Wcalc(j)
    j ← j + 1
end while
SNR_eff = {SNR_eff[0], SNR_eff[1]}
l_optimal = {l_optimal[0], l_optimal[1]}
m_optimal = {m_optimal[0], m_optimal[1]}
return
Mapping of SNR_eff to CQI value
Mapping of l_optimal to RI value
Mapping of m_optimal to PMI value
```

IV. Simulations Results

This section presents simulation results obtained with a standard compliant LTE-A physical layer simulator [4]. The simulation parameters are summarized in Table I. Fig 2 illustrates how the throughput changes with the SNR considering a 4×4 MIMO scenario, and schemes with or without CA. The feedback delay is equal to 0 and ETU block fading channel model is assumed in each of the three scenarios, respectively. The simulation results clearly show the significant

TABLE I
SIMULATION PARAMETERS

Simulation Parameters	**Macro**	**Pico 1**	**Pico 2**
Subframes	30	30	30
Channel	EPA	EPA	EPA
Bandwidth (MHz)	5	10	15
CC's frequency (MHz)	900	1800	2500
No. of BS antennas	4	4	4
No. of UE antennas	4	4	4
MIMO technique	CLSM	CLSM	CLSM
MIMO decoder	ZF	ZF	ZF
PMI feedback granularity	50	75	75
CQI feedback granularity	50	75	75
Subcarrier spacing (kHz)	15	15	15
CFO	π	π	π
Feedback delay in TTIs	0, 1, 2	0, 1, 2	0, 1, 2

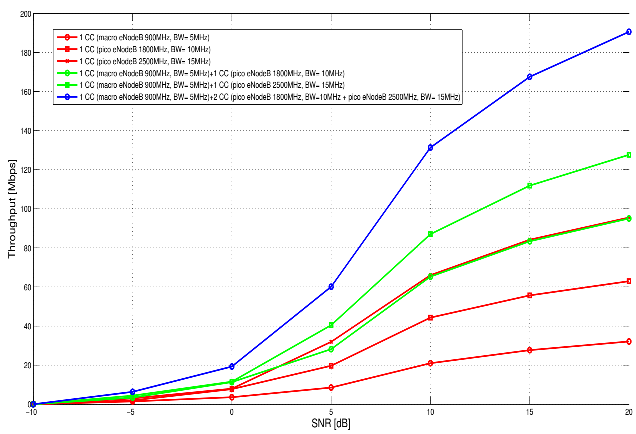

Fig. 2. Throughput vs SNR considering ETU channels and 0 TTI feedback delay.

increase in the system's throughput, when multiple antennas are employed both at the transmitter and the receiver. Specifically, the throughput for 4×4 scenario with CA is the sum of data rates of each CC. Note that by using the same equipment at the eNodeBs and UE, CA technique seems to be an exceptional tool to increase the overall capacity in heterogeneous environments.

In Figs. 3 and 4 system throughput is plotted against the SNR obtained for this setup, assuming an ETU block fading channel model and feedback delay equal to 1 or 2 TTI, respectively. As expected a throughput degradation occurs due to the non-zero feedback delay, which is worse in lower SNR values. Moreover, it should be noted that the degradation is significantly lower when CA is considered.

ACKNOWLEDGEMENTS

This work was carried out and funded within the framework of SOLDER ICT-619687 FP7 STREP project (2013-2016).

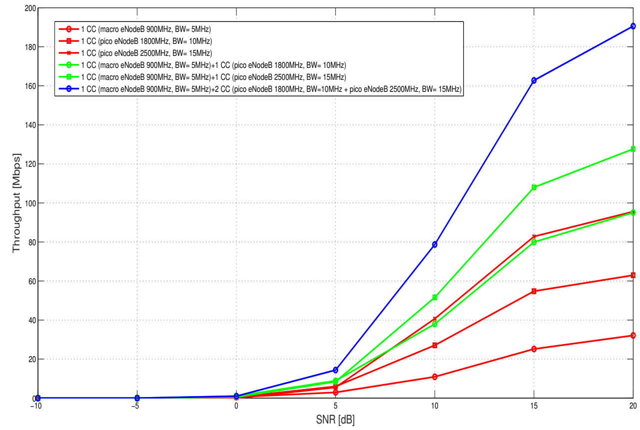

Fig. 3. Throughput vs SNR considering ETU channels and 1 TTI feedback delay.

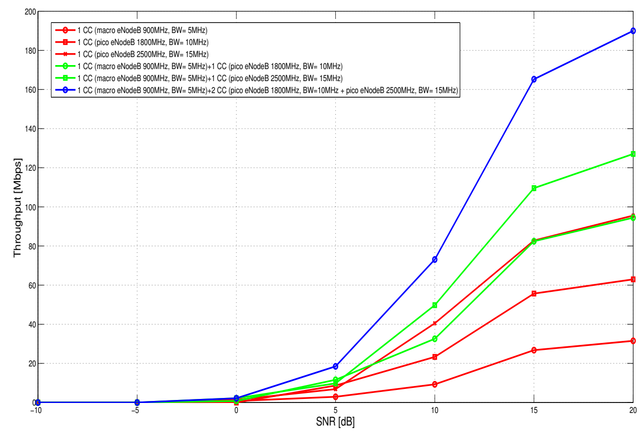

Fig. 4. Throughput vs SNR considering ETU channels and 2 TTI feedback delay.

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