Cooperation Strategies for Multi-user Transmission in Manhattan Environment*

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Abstract: One of the major drawbacks for wireless communication systems in Manhattan environment with tall buildings lining both sides of the streets is the performance degradation caused by the penetration loss and the effects of inter-sector interference. To overcome such a degradation, cooperation among the sectors is under an active investigation as an efficient means to provide an enhanced coverage as well as increased spectral efficiency. In this paper, we describe various type of cooperation sector location for cooperative multi-user transmission, and determine cooperation strategies for the cooperative operation among sectors by evaluating and comparing the types of microcell in Manhattan environment. The results shows that the more suitable number of cooperation sectors is determined by signal-to-interference plus noise ratio (SINR), outage probability, and throughput comparison. Performance variations based on different numbers of sector density under cooperation are also presented to suggest an efficient inter-sector cooperative transmission strategy in Manhattan environment.

1 INTRODUCTION

In wireless communication systems, mobile user's demands are rapidly increasing for high data rate and quality network services in urban areas. Urban micro-cellular system in Manhattan-like environment have difference features, compared with macro-cellular systems. The micro-cellular network requires higher system capacity for the dense traffic channel, where a significant amount of access users to wireless link occurs. The micro-cellular system is developed in the metropolitan area, where tall buildings are aggregated and lined both sides of the streets. Thus, the propagation models of line-of-sight (LOS) and non line-of-sight (NLOS) wireless channel between base-stations (BSs) and mobile-stations (MSs) are adopted for practical performance investigations.

The performance evaluation of micro-cellular networks in Manhattan-like environment and related works have been widely studied. Standardization groups of IEEE802.16m and 3GPP-LTE advanced are also developing the next generation cellular systems considering Manhattan environment. Capacity and interference statistics of street cross-shaped micro cells is analyzed in (Ahmed, 2003), and spatial multiple-input multiple-output (MIMO) channel capacity statistics in Manhattan environment are represented (Chizhik, 2003). The efficient resource control and channel allocation method are also proposed. Considering user mobility characteristics, the performance focused on average number of handoffs has been analyzed by (Cho, 2000). The propagation model and deployment strategies of transmitters was suggested in (Chiu, 2009), and multi-hop relay networks in Manhattan-like environment is investigated in (Fu, 2007). However, these studies are based on the non-cooperative operation among BSs without considering the cooperative transmission and interference mitigation.

In this paper, we present the efficient cooperation strategy in Manhattan environment from the performance investigation of the cooperative multi-user transmission. First, the various cooperation strategies are presented as increasing the number of cooperation sector antennas, where the uniformly distributed MSs are located along the cross shape street considering the urban micro-cellular model of IEEE802.16m system. For the different BS density in this environment, cooperation scenarios according to the cooperation sector antenna variation are also described. Second, the presented cooperation strategies are applied to cooperative multi-user transmission using zero-forcing beamforming and their performance in terms

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of signal-to-interference plus noise ratio (SINR), outage probability, and throughput is compared, with an aim of determining a feasible cooperation strategy in Manhattan environment. Third, the performance variations based on different numbers of BS density and the cooperative multi-user transmission scheme are evaluated, to confirm the performance manner in different operational settings.

The organization of the paper is as follows. Section II gives the system model for the cooperative multi-user transmission and the propagation model in Manhattan environment. In Section III, cooperation scenarios are explained as the variation based on the number of cooperation sector antennas and BS density. The performance results are compared and investigated in Section IV. Concluding remarks are given in Section V.

2 SYSTEM MODEL

2.1 Channel Propagation Model

Manhattan network consists of 100 buildings and 41 BSs with 4-sector antennas, as shown in Fig. 1. The building block size is $200m \times 200m$ and the street width are set to be $30m$. BSs are located at the main street-crossing, which are positioned at every two intersection (BS density $\eta = 1/2$). A BS with 4-sector antennas covers 4 building blocks including a cross-shaped area and a cell coverage is about 430×430 square meters. All cooperative BS sets are assumed to use the same multi-user transmission scheme. MSs located uniformly distributed along streets and never enter the buildings considering outdoor environment only.

2.2 Signal Model

We consider downlink transmission from sector BSs with single transmit antennas to target MSs equipped with single receive antennas in Manhattan environment. For the cooperative multi-user transmission using N_S sector BSs, the i-th sector antenna of the l-th cooperation set is denoted by $\mathrm{BS}_i^{(l)}$, and $\mathrm{MS}_k^{(l)}$ denotes the k-th MS among N_M MSs communicating with a given l-th group of cooperating sector BSs.

In general, the signal model for a cooperative multi-user transmission with N_S single antenna sectors and N_M single antenna MSs is given by

$$\mathbf{r} = \mathbf{H}^{(c)}\mathbf{W}^{(c)}\mathbf{s}^{(c)} + \sum_{l \neq c} \mathbf{H}^{(l)}\mathbf{W}^{(l)}\mathbf{s}^{(l)} + \mathbf{n} \qquad (1)$$

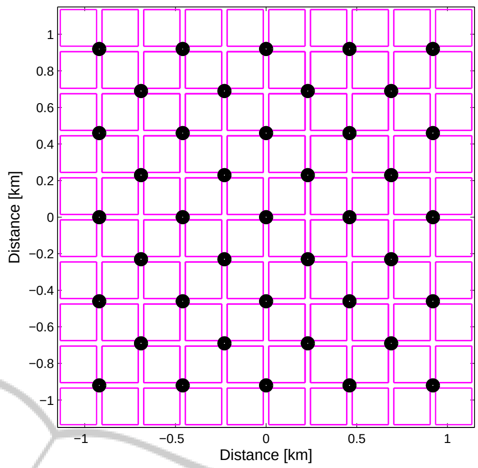

Figure 1: Manhattan deployment scenario.

where l denotes the index of the cooperation set, and $\mathbf{H}^{(l)}$, $\mathbf{W}^{(l)}$, and $\mathbf{s}^{(l)}$ are the $N_M \times N_S$ channel matrix, corresponding $N_S \times N_S$ precoding matrix for the cooperative multi-user transmission, and $N_S \times 1$ transmit signal vector from the cooperative BSs of the l-th cooperation set, respectively. $\mathbf{n}$ denotes an additive white Gaussian noise (AWGN) vector and c is the index of the desired cooperation set.

2.3 MIMO Transmission

Cooperative ZF. In this paper, we consider the cooperative multi-user transmission using zero-forcing beamforming. By utilizing the pseudo-inverse matrix $\mathbf{W} = \mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}$ for the channel matrix, zero-forcing beamforming efficiently nulls transmission.

Cooperative zero-forcing beamforming is the practical multi-user MIMO scheme for enhancing the bandwidth efficiency with multiple data transmission and mitigation of the multi-user interference, simultaneously. However, cooperative zero-forcing beamforming is not able to use full power transmission at each sector which is subject to per antenna power constraints. It is shown that one of the sector antenna among cooperative sectors always use full power. The probability of signal power for the other sector antenna is distributed at the transmit power range below the normalized maximum power value '1', and the probability of the low power transmission increases as the number of cooperation sectors. Thus, the transmit signal from the other sectors, where a transmit antenna utilizes lower transmit power than the maximum value '1', impairs the cooperative channel gain and SINR performance of the cooperative zero-forcing beamforming.

Cooperative ZF-DPC. Cooperative zero-forcing dirty paper coding is a non-linear scheme for the multi-user MIMO transmission, which can utilize the full power transmission. For cooperative zero-forcing dirty paper coding from N_S sectors to N_M multiple MSs, the LQ decomposition of the channel matrix $\mathbf{H}$ can be utilized to transmit the multiple data for multiple MSs, and dirty paper coded transmit signal nulls out the inter-user interference signal. Using LQ decomposition, can be decomposed as $\mathbf{H} = \mathbf{LQ}$, $\mathbf{L}$ is $N_M \times N_S$ lower triangular matrix and triangular matrix and $\mathbf{Q}$ is $N_S \times N_S$ unitary matrix. For cooperative zero-forcing dirty paper coding, the diagonal elements of the lower triangular matrix $\mathbf{L}$ are beamforming gain and the unitary matrix $\mathbf{Q}$ can be used for $\mathbf{W} = \mathbf{Q}^H$.

3 COOPERATION STRATEGIES

In Manhattan street environment, we consider the BS collaboration which contains sector antennas to transmit signal for MSs located at the outdoor street. At the center of the intersection, 4-sector antennas of a BS transmit signal to target MSs, and a target MS can receive the desired sinal from a serving sector antenna, when a MS is selected by scheduling among uniformly distributed MSs in the coverage area of each sector antenna. Thus, the number of cooperative serving sectors is same as the number of target MSs ($N_S = N_M$), and it is to be determined how many sector antenna can be utilized for the efficient cooperation strategy.

To determine the efficient cooperation strategy, the SINR distributions are evaluated and compared using the 2, 4, 8, and 16-sector cooperation models using full frequency reuse. The signal is transmitted from each sector with 40 dBm power over the flat Rayleigh fading channel. The thermal noise of -104 dBm power is added at the receiver, which corresponds to 10 MHz transmission bandwidth of 2 GHz center frequency. We assume the MSs of interest is located along the street of the coverage area for a center cooperation group in Manhattan grid network, and both the transmitter and receiver have the perfect knowledge of the channel. Employing the cooperative zero-forcing transmission, each cooperation sector is subject to per antenna power constraints.

The topology of cooperative sector antennas and collaboration strategies can be presented by various scenarios according to the BS density (η) variation. As the variation of the BS density, these topologies of sector BSs for the cooperative transmission, which is adopted for the regular pattern of the cooperation group in entire Manhattan grid network, are chosen

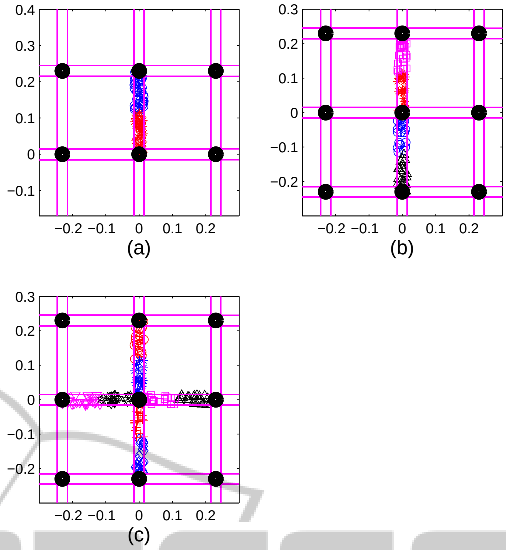

Figure 2: Cooperation scenarios for the BS density $\eta = 1$: (a) 2-sector cooperation, (b) 4-sector cooperation, (c) 8-sector cooperation.

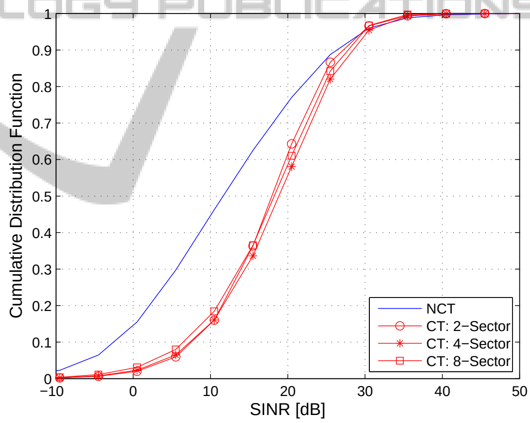

Figure 3: SINR performance for the cooperative zero-forcing transmission (η = 1).

for the performance comparison.

Case I ($\eta = 1$). Considering the maximum BS density, Each BS is located at every intersection, where the distance between the nearest two BSs is 230*m*. In this case, a sector coverage is about 230×100 square meters including 100×30 street area. The topology of 3 cooperation scenarios; (a) 2-sector collaboration facing each other at edge points of the straight line street, (b) 4-sector collaboration of 3 BSs located at a center point and 2 edge points of the straight line street, and (c) 8-sector collaboration of 5 BSs located at a center point and 4 edge points of the cross-shaped street area can be presented.

The cumulative distribution functions (CDFs) of the SINR for cooperative zero-forcing beamforming

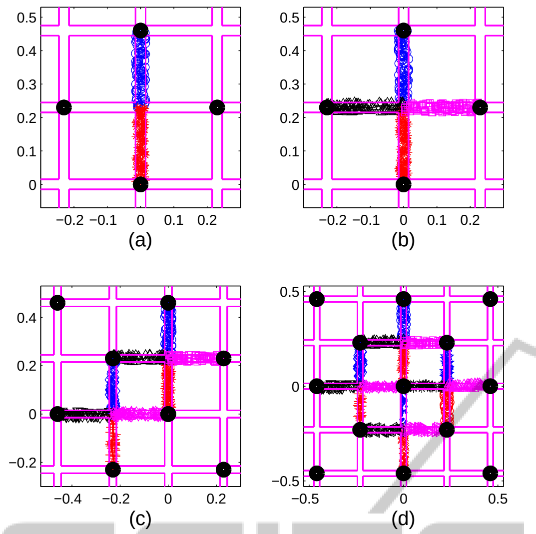

Figure 4: Cooperation scenarios for the BS density $\eta = 1/2$: (a) 2-sector cooperation, (b) 4-sector cooperation, (c) 8-sector cooperation, (d) 16-sector cooperation.

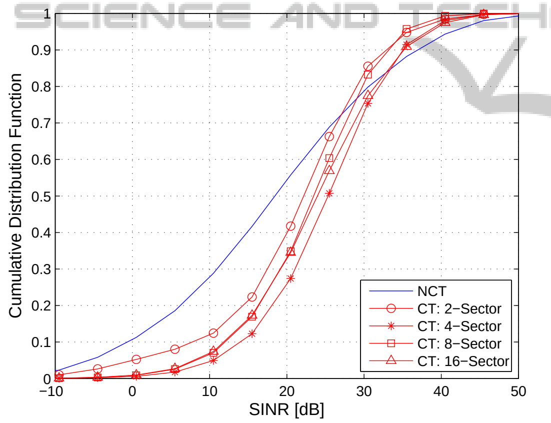

Figure 5: SINR performance for the cooperative zero-forcing transmission (η = 1/2).

using different the number of cooperation sectors are plotted in Fig. 3. The SINR performance gain of cooperative transmission using 4-sector antennas over the non-cooperative transmission amounts to 7 dB at the median value of 0.5, demonstrating the inter- and intra-cooperation sector interference signal reduction performing cooperative multi-user transmission. However, it is observed that no noticeable gain is obtained by performing 2-sector and 8-sector cooperation over 4-sector cooperation, since the interference impact cannot be significantly reduced under the maximum BS density condition.

Case II ($\eta = 1/2$). The Manhattan deployment scenario in Fig. 1 and 4 employ the BSs location at every two intersection ($\eta = 1/2$), where the horizontal or vertical distance along the street between two BSs is 460m. A sector antenna covers 2 building blocks including 200×30 street area and a sector coverage is about 430×200 square meters. The topology of 4 cooperation scenarios; (a) 2-sector collaboration facing each other at edge points of the straight line street, (b) 4-sector collaboration of 4 BSs located at 4 edge points of the cross-shaped street area, (c) 8-sector collaboration of 6 BSs located at connected cross-shaped streets of a parallelogram area, and (d) 16-sector collaboration of 9 BSs located at a diamond shape area can be presented.

In Fig. 5, it can be observed that 4-sector cooperation outperforms 2, 8, 16-sector cooperation. It is also shown in the figure that SINR of cooperative transmission is substantially higher than that of the non-cooperative transmission. At the median value of 0.5, the amount of SINR gain for 4-sector cooperation exceeds 7.4 dB when compared to non-cooperative transmission.

4 PERFORMANCE COMPARISON

In this section, the per-user throughput, total throughput, and outage probability are evaluated and compared with 4 and 8-sector cooperation models using full frequency reuse.

Figure 6 shows the CDFs of the per-user throughput for different BS density of 4-sector and 8-sector cooperation. The per-user throughput can be obtained by $\frac{1}{N_M}\sum_{k=1}^{N_M}\log_2(1+\gamma_k)$, where γ_k is the SINR value of $\mathrm{MS}_k^{(c)}$. It is confirmed that 4-sector cooperation exhibits the maximum per-user throughput for all cases of the BS density. The per-user throughput performance is enhanced as decreading the BS density, since the signal power from the interfering cooperation sector is reduced by the sparse number of BS. In particular, the performance gap between 4-sector and 8-sector cooperation increases at the large BS densisty.

The distributions for the total throughput considering the BS density variation are plotted in Fig. 7. The total throughput can be quantified by the sum of throughput for every MS in about 2.6×2.6 square kilometers area. Increasing the BS density, the target MSs received the desired signal are densily located in the considering area. At the cooperation coverage area of $eta = 1/4$ case for 4 MSs, 16 MSs can be located to receive the desired signal considering $eta = 1/2$ case. Thus, it is observed that the total throughput is improved by the large BS density con-

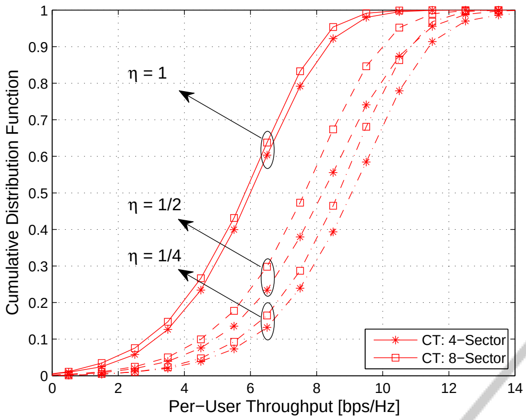

Figure 6: Per-user throughput for the cooperative zero-forcing transmission.

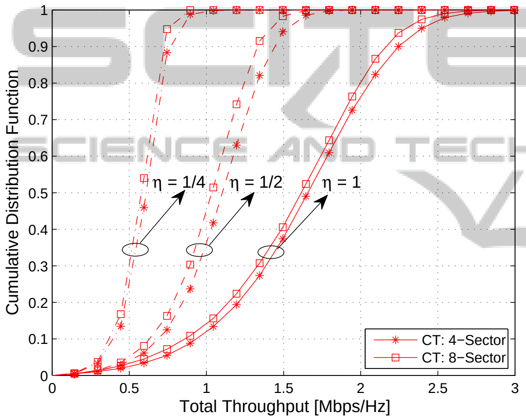

Figure 7: Total throughput for the cooperative zero-forcing transmission.

dition due to the high link-access capability of MSs.

The performance of the outage probability is evaluated and compared condiering the BS density variation. At the entire range of outage threshold γ_{th}, BS density $eta = 1/4$ using 4-sector cooperation exhibits the minimum outage probability, where the amount of the strong interference signal is reduced by the sparseness of BSs. At the 0.1% outage probability, the SINR gain for the 4-sector cooperation of $eta = 1/4$ case exceeds 6 dB when compared to $eta = 1$ case.

Employing the cooperative zero-forcing dirty paper coding, the performance of the effective SINR and the outage probability are evaluated using the 2, 4, 8, 16-sector cooperation models for BS density $\eta = 1/2$, when all of the cooperation sectors use full power transmission.

5 CONCLUSION

In Manhattan environment, we describe the various kinds of cooperation strategy as increasing the number of cooperation sectors and transmission node density of the network. Considering both the practical linear scheme using cooperative zero-forcing beamforming and non-linear scheme using zero-forcing dirty paper coding, it is determined that 4-sector cooperation can be feasible strategy for cooperative multi-user transmission in Manhattan network.

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