Massive Notes 1.9

Key Points : Basic Concept of SDMA; M-MMSE

1. Basic Concept of SDMA

1. In the previous notes, we talked about 1) increasing the transmit power or 2) using multiple BS antennas can only bring **modest** improvements to the UL SE. The main reason of this is these methods improve the **SINR**, which appears **INSIDE** the logarithm of the SE expression, thus the SE increases **SLOWLY**.

2. Therefore, we would like to identify a way that improves the SE at the **OUTSIDE** of the logarithm instead.

3. Let's recall the SE expressions of LoS and NLoS. Firstly, consider the SISO case, then we have

$$\mathrm{SE}_0^{\mathrm{LoS}} = \log_2\big(1 + \frac{1}{\bar{\beta} + \frac{1}{\mathrm{SNR}_0}}\big) = \log_2\big(1 + \frac{1}{\bar{\beta} + \frac{\sigma^2}{p\beta_0^0}}\big) \tag{1}$$

$$\mathrm{SE}_0^{\mathrm{NLoS}} = \mathbb{E}\big\{\log_2\big(1 + \frac{p|h_0^0|^2}{p|h_1^0|^2 + \sigma^2}\big)\big\} = \frac{e^{\frac{1}{\mathrm{SNR}_0}} E_1(\frac{1}{\mathrm{SNR}_0}) - e^{\frac{1}{\mathrm{SNR}_0\bar{\beta}}} E_1(\frac{1}{\mathrm{SNR}_0\bar{\beta}})}{\log_e(2)(1-\bar{\beta})} \tag{2}$$

then consider SIMO case

$$\mathrm{SE}_0^{\mathrm{LoS}} = \log_2\big(1 + \frac{M}{\bar{\beta} g(\varphi_0^0, \varphi_1^0) + \frac{1}{\mathrm{SNR}_0}}\big) = \log_2\big(1 + \frac{M}{\bar{\beta} g(\varphi_0^0, \varphi_1^0) + \frac{\sigma^2}{p\beta_0^0}}\big) \tag{3}$$

$$\mathrm{SE}_0^{\mathrm{NLoS}} = \left(\frac{1}{(1-\frac{1}{\bar{\beta}})^M} - 1\right) \frac{e^{\frac{1}{\mathrm{SNR}_0\bar{\beta}}} E_1(\frac{1}{\mathrm{SNR}_0\bar{\beta}})}{\log_e(2)}$$
$$+ \sum_{m=1}^{M} \sum_{l=0}^{M-m} \frac{(-1)^{M-m-l+1}}{(1-\frac{1}{\bar{\beta}})^M} \frac{\left(e^{\frac{1}{\mathrm{SNR}_0}} E_1(\frac{1}{\mathrm{SNR}_0}) + \sum_{n=1}^{l} \frac{1}{n} \sum_{j=0}^{n-1} \frac{1}{j!\mathrm{SNR}_0^j}\right)}{(M-m-l)!\mathrm{SNR}_0^{M-m-l}\bar{\beta}\log_e(2)} \tag{4}$$

4. Since the logarithmic expressions in (1) to (4) describe the SE of the channel between a particular UE and its serving BS, we can potentially serve **MULTIPLE** UEs, say K UEs, simultaneously in each cell and achieve a **sum SE** that is **the summation of K SE expressions** of the types in (1) to (4).

5. An obvious bottleneck of such multiplexing of UEs is the **Co-user Interference** that increase with K and now appears also **WITHIN** each cell (i.e., intra-cell interference). The intra-cell interference can me much stronger than the inter-cell interference and needs to be **suppressed** if a K-fold increase in SE is actually to be achieved.

6. **SDMA** is short for **Space-Division Multiple Access**, which aims to handle the co-user interference in a cell by using multiple antennas at the BS to reject interference by spatial processing. Then the terminology **Multiuser MIMO** was used.

7. **Multiuser MIMO** means the K UEs are multiple inputs and the M antennas in a BS are the multiple outputs. Therefore, multiuser MIMO is used **irrespective** of how many antennas each UE is equipped with.

2. UL SDMA Transmission Model

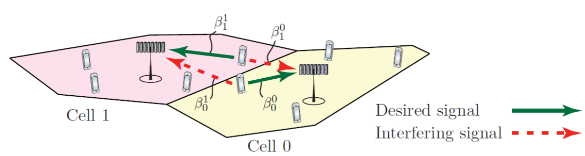

Figure.1 K active UEs in each cell.

8. Consider there are K active UEs in each cell just as Figure. 1, and the channel response between the kth desired UE in cell 0 and the serving BS is denoted by $\mathbf{h}_{0k}^{0} \in \mathbb{C}^{M}$ for $k = 1, \ldots, K$, the subscript $0k$ means this channel response is from the kth UE, and this UE is in the cell 0. The superscript 0 indicates the BS in cell 0. Therefore, $\mathbf{h}_{1k}^{0}$ refers to the channel response between the kth UE in the cell 1 and the BS in cell 0. So the received multiantenna UL signal is the generalized to

$$\mathbf{y}_0 = \underbrace{\sum_{k=1}^{K} \mathbf{h}_{0k}^{0} s_{0k}}_{\text{Desired signals}} + \underbrace{\sum_{k=1}^{K} \mathbf{h}_{1k}^{0} s_{1k}}_{\text{Interfering signals}} + \underbrace{\mathbf{n}_0}_{\text{Noise}} \tag{5}$$

9. The LoS channel response for UE k in the cell j is

$$\mathbf{h}_{jk}^{0} = \sqrt{\beta_j^0}\left[1, e^{2\pi \mathrm{j} d_{\mathrm{H}} \sin(\varphi_{jk}^0)}, \ldots, e^{2\pi \mathrm{j} d_{\mathrm{H}}(M-1)\sin(\varphi_{jk}^0)}\right]^{\mathrm{T}} \quad \text{for} \quad i = 0, 1 \tag{6}$$

where $\varphi_{jk}^0 \in [0, 2\pi)$ and $\mathbf{h}_{jk}^0 \sim \mathcal{N}_{\mathbb{C}}(\mathbf{0}_M, \beta_j^0 \mathbf{I}_M)$ and assumed to be statistically independent between UEs.

10. The problem we face now is when BS received the superposition signal from K desired UEs, how to **separate** those UEs in the spatial domain. In other words, how to **direct** its hearing towards the location of each desired UE.

3. M - MMSE

11. Suppose the BS in the cell 0 can use knowledge of its kth UE's channel response to **TAILOR** a receive combining vector $\mathbf{v}_{0k} \in \mathbb{C}^M$ to this UE channel. This vector is multiplied with the received signal (5) to obtain

$$\mathbf{v}_{0k}^{\mathrm{H}} \mathbf{y}_0 = \underbrace{\mathbf{v}_{0k}^{\mathrm{H}} \mathbf{h}_{0k}^0 s_{0k}}_{\text{Desired signal}} + \underbrace{\sum_{i=1, i \neq k}^{K} \mathbf{v}_{0k}^{\mathrm{H}} \mathbf{h}_{0i}^0 s_{0i}}_{\text{Intra-cell interference}} + \underbrace{\sum_{i=1}^{K} \mathbf{v}_{0k}^{\mathrm{H}} \mathbf{h}_{1i}^0 s_{1i}}_{\text{Inter-cell interference}} + \underbrace{\mathbf{v}_{0k}^{\mathrm{H}} \mathbf{n}_0}_{\text{Noise}} \tag{7}$$

12. So what is $\mathbf{v}_{0k}$ should be? We may remember MRC, then we have

$$\mathbf{v}_{0k} = \mathbf{h}_{0k}^0 \tag{8}$$

but it is not the optimal choice. In fact, the optimal vector is **Multicell Minimum Mean-Squared Error(M-MMSE)** as follows

$$\mathbf{v}_{0k} = p\left(p \sum_{i=1}^{K} \mathbf{h}_{0i}^0 (\mathbf{h}_{0i}^0)^{\mathrm{H}} + p \sum_{i=1}^{K} \mathbf{h}_{1i}^0 (\mathbf{h}_{1i}^0)^{\mathrm{H}} + \sigma^2 \mathbf{I}_M\right)^{-1} \mathbf{h}_{0k}^0 \tag{9}$$

12. M-MMSE combining maximizes the SINR by finding the best **balance** between amplifying the desired signal and suppressing interference in the spatial domain. The price to pay is the **increased computational complexity** from inverting a matrix and the need to learn the matrix that is inverted in (9). (END)