Massive MIMO (multiple-input, multiple-output)

1. Spectral Efficiency versus the Number of Services Antennas

In figure 10 of the reference "MASSIVE MIMO: AN INTRODUCTION", total spectral efficiency is shown as a function of the number of antennas in the transmitter for k=[16 32 64 128]. It is assumed that the transmitter has perfect CSI. Massive MIMO performance is computed as a capacity lower-bound for conjugate beamforming according to bellow formula:

$$C_{sum\,cb} > K\log_2(1+\frac{M\rho_d}{K(1+\rho_d)})$$

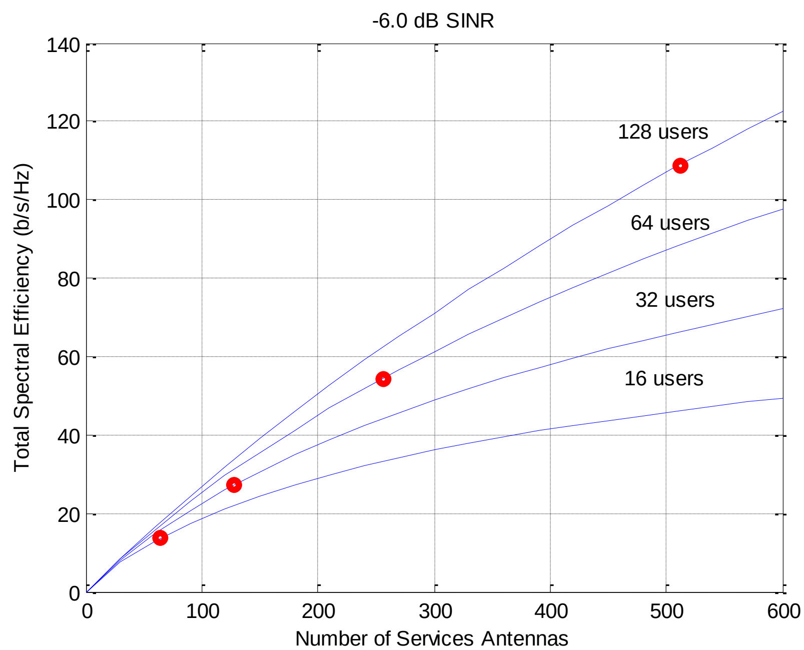
The reds X's correspond to the dimensions, M = 4K. The point (M,K)=(64,16) yields a total spectral efficiency of 13.6 bits/s/Hz, which is doubled for every simultaneous doubling of (M,K). The Point-to-Point MIMO performance is ergodic Shannon capacity according to the following equation:

$$C = \log_2(I_K + \frac{\rho_d}{M}G_d^H G_d) \;= \log_2(I_M + \frac{\rho_d}{M}G_d G_d^H)$$

- **Matlab Codes**

```
%%%%%% spectral efficiency versus number of BS antennas for K = 16, 32, 64,
128 users operating at a minus 6 dB SINR.
clear all
clc
p=10^(-0.6);
M=0:30:600;
for c=4:7
    k=2^c;
    Csumcb=k*log(1+M*p/(k*(1+p)))/log(2);
    plot(M,Csumcb,'LineWidth',1)
    hold on
end
%%%%Specifying the effect of doubling the number of antennas of base
statiions and the number od users simultaneously
for a=4:7
    M=2^(a+2);
    k=2^a;
    Csum=k*log(1+M*p/(k*(1+p)))/log(2);
    plot(M,Csum,'ro','LineWidth',5,'MarkerSize',2)
    hold on
end
xlabel('Number of Services Antennas')
ylabel('Total Spectral Efficiency (b/s/Hz)')
title('-6.0 dB SINR')
gtext('16 users')
gtext('32 users')
gtext('64 users')
gtext('128 users')
grid on
```

➢ Simulation Result



2. Sum Rate versus Number of BS Antennas

Figure 11 of reference shows the sum rate of K = 16 users as a function of the number of BS antennas for 0 dB SINR using linear precoding in Massive MIMO. The other curve again shows the sum rate but by using dirty-paper coding.
By comparing these two curves, it is received that the linear precoding used in Massive MIMO is highly competitive with the dirty-paper coding mandated by Shannon theory.
A lower bound for linear precoding can be as the following:

$$C_{sum\,zf} > K\log_2(1+\frac{(M-K)\rho_d}{K})$$

The Shannon limit is computed according to:

$$C_{sum\,down} = \sup_a\{\log_2\det(I_M+\rho_d G_d D_a G_d^H)\},$$

$$a \geq 0, I^T a = 1$$

➢ Matlab Codes

```
%%%%% Total spectral efficiency versus number of BS antennas for K = 16 users
and 0.0 dB SINR.
clear all
clc
K=16;
P=1;
j=0;
M=20:2:100;
A=K*log(1+(M-K)*P/K)/log(2);
```

```
plot(M,A)
hold on
for M=20:100;
        for i=1:M
            H=exprnd(0.25);
            j=j+H^2;
        end
    Sumrate=K*log(1+(P./M)*j)/log(2);
    plot(M,Sumrate,'r*','LineWidth',2,'MarkerSize',4)
    hold on
end
title('0 dB SINR,K=16')
xlabel('Number of BS antennas (M)')
ylabel('Sum Rate (bits/s/Hz)')
gtext('Lower Bound(ZF/CB)')
gtext('Shannon Limit(DPC)')
grid on
```

- **Simulation Result**