EE620: MIMO Wireless Communications
Term project

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Question 1: Survey:

IEEE 802.11 Standards:

Wi-Fi is the technology of the hour which has changed the communication paradigm as we see it today with connectivity over a number of devices. Of the WLAN solutions that are available, the IEEE 802.11 is the most accepted of all. These standards cover all aspects of wireless communications – amendments for higher data rates, handovers, security, power management, quality of service, etc.

- 802.11a – The standard specifies specifications for wireless communication in the 5 GHz ISM band with data rate up to 54 Mbps.
- 802.11b - The standard specifies specifications for wireless communication in the 2.4 GHz ISM band with data rates up to 11 Mbps.
- 802.11e – The standard is an amendment to provide specifications for a desired Quality of service
- 802.11f – The standard is an amendment to provide specifications for an efficient Handover mechanism.
- 802.11g - The standard specifies specifications for wireless communication in 2.4 GHz ISM band with data rates up to 54 Mbps.
- 802.11h - The standard provides specifications for efficient power control.
- 802.11i - The standard provides specifications for authentication and encryption targeting the security issues in the ISM band.
- 802.11j - The standard provides specifications for interworking.
- 802.11n - The standard specifies specifications for wireless communication in the 2.4 and 5 GHz ISM bands with data rates up to 600 Mbps with the introduction of MIMO to Wi-Fi technology.
- 802.11ac - The standard specifies specifications for wireless communication below 6GHz to provide data rates of at least 1Gbps per second for multi-station operation and 500 Mbps on a single link. The standard was the first to implement MU-MIMO with efficient TX- beamforming as will be discussed later.
- 802.11ad - The standard specifies specifications for wireless communication with very high throughput at frequencies up to 60GHz so that interference levels are low. The standard makes use of frequencies in the millimeter range as it is aimed at short rang communications for high volume of data.
- 802.11ax – The standard provides specifications as an improvement over 802.11ac to achieve data rates corresponding to 10 Gbps using MU-MIMO with OFDA as will be discussed later.

MIMO Technology Specification:

802.11n:

802.11n provides a major improvement on the throughputs, typically upto 600 Mbps (Over-the-air-estimates). This significant advancement to the Wi-Fi technology was introduced by employing multiple antennas at both the transmitter and receiver each of which transmits a different spatial streams. A new multiplexing scheme was introduced call **Spatial Division Multiplexing** (SDM). Without SDM, the standard maxes out at 150 Mbps. But by increasing the number of antennas at each end, and employing efficient SDM can help us achieve 300 and 450 Mbps. Hence, use of SDM showed a considerable increase in the data throughput. These techniques coupled with exploitation with **spatial diversity** (by using space time codes) helped in increasing the range.

It was observed that systems employing 4 antennas, each transmitting a different spatial streams over a channel width of 40 MHz, delivered a throughput that reached 600 Mbps. The standard specifies systems involving **2 x 2: 2; 2 x 3: 2; 3 x 2: 2; 4 x 4: 4; 3 x 3: 3.** (where a x b:c denotes a system with a transmitter, b receivers and c data streams). However, the increase in throughput is restricted by the number of spatial streams which is further restricted by the number of antennas at either end. As mentioned above the standard allows the use of upto 4 antennas on each end, giving a liberty on the combination eg. 2 x 3, 3 x 2, in such cases the **surplus antenna** can be used to provide appropriate **antenna diversity.**

Parameter	*Specification*
Channel bandwidth	20 MHz, 40 MHz
Modulation	CCK, DSSS, OFDM
Spatial Streams (MIMO)	1 TO 4, codes like Alamouti Coding

Table 1: 802.11n Standard Specifications

Advantages:

- Greater speed ~ 600Mbps without increase in spectral consumption
- Effective in dealing with multipath signals, and use it to advantage to increase reliability.

802.11ac:

Even though IEEE 802.11n showed considerable increase in throughput from the earlier versions using MIMO, it had a limitation which severly reduced the trhoughput of the system. The 802.11n standard can be viewed as a Single User- MIMO (SU-MIMO) which is capable of transmiting multiple spatial streams but directed to single client or user. Therefore, in presence of multiple users, the throughput would reduce with an increase in the number of user as rightly shown in fig.1. 802.11ac tackles the problem by adding a channel access method to the MIMO called **Space Division Multiple access** (SDMA) and **TX beam forming**. Thus giving rise to a concept of MU-MIMO, which does not compromise on the throughput upto a certain number of simultaneous users.

MIMO Design Considerations:

The design considerations and the corresponding specifications depend upon three parameters – **number of spatial streams**, **number of simultaneous users** and efficient **TX beamforming**.

- 802.11ac increases the number of MIMO **streams to 8**, thus aiming to double the network capacity achieved in 802.11n. However to achieve full MIMO potential, an 8x8 AP should requires 8x8 client configuration which is impractical. MU – MIMO allows multiple 1x1 and 2x2 mobile clients to share the maximum of 8 data streams to efficiently use the available capacity.

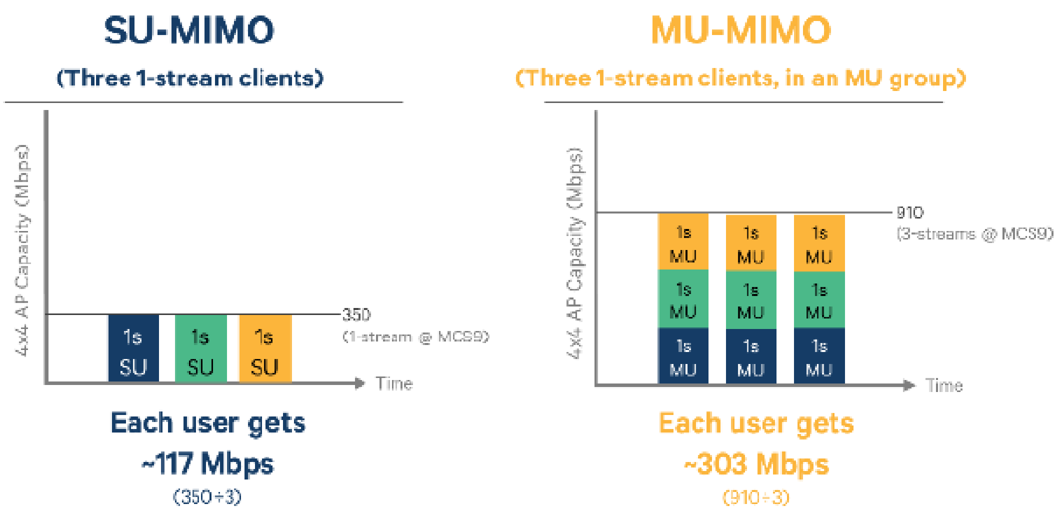

Figure 1: SU MIMO vs MU MIMO Throughput comparison

- 802.11ac specifies a maximum of **4 simultaneous MIMO channels** (users). To enable MU-MIMO, the users feedbacks the channel information which the AP uses to efficiently direct its spatial streams. MU-MIMO beam forming, capabilities are used to maximize signal strength in the direction of the desired user and nulling it in the direction of others.
- Owing to the tradeoffs, the best MU-MIMO performance can be achieved by employing a 4x4 system with 3 simultaneous users. Implementation of **4 antennae 3 user N+1 AP** using enhanced beamforming and nulling techniques like **Singular Value Decomposition (SVD) beamforming** enhanced data rate can be achieved.

Parameter	*Specification*
Channel bandwidth	20 MHz, 40 MHz, 80 MHz, 160 MHz, 80-80 MHz
Modulation	BPSK, QPSK, 16/64/256-QAM
Spatial Streams (MIMO)	1 TO 8 – TX beamforming, STBC, MU-MIMO

Table 2: 802.11ac Standard Specifications

Advantages:

- Increased Data rate ~ 1300 Mbps (max ~ 6.93 Gbps)
- More users / more traffic per system
- Increased Spectral Efficiency ~ typically by a factor of 2-3x.

802.11ax:

The standard is yet to be released as an improvement over the 802.11ac (Est. 2019). The most important feature that it is going to incorporate is MIMO- OFDA (where OFDA ~ orthogonal frequency division access). 802.11ax specifies 4 MIMO spatial streams, each stream multiplexed with OFDA. Huawei claims an increase in spectral efficiency typically with a factor of 10. Data rate of upto ~ 2 Gbps (Max ~ 10 Gbps).

Future Techniques:

Sub-Band OFDMA: The technique is an multi user adaptation of the popular OFDM scheme which can be combined MIMO to attain higher data rates and high reliability. Employing sub band OFDMA can improve channel utilization efficiency by proper scheduling of resource allotment.

Uplink MU- MIMO: Current MU-MIMO systems supports only support mostly downlink, however keeping the window open for MU-MIMO implementation in the uplink. The challenges are to determine the synchronization of the timing offset of the users and compensate frequency offsets between users. Thus by tackling these problems, we can reduce the contentions in the packet being transmitted from the user to the AP, and thus achieve high throughput for uplink too.

References:

[1] Qualcomm Atheros Inc. "*802.11ac MU-MIMO: Bridging the MIMO Gap in Wi-Fi*", January 2015.

[2] Joonsuk Kim and Inkyu Lee, "*802.11 WLAN: History and New Enabling MIMO Techniques for Next Generation Standards*" in IEEE Communications Magazine, March 2015, Pg. 134-140.

[3] Intel Content, "*Helping Define IEEE 802.11 and other Wireless LAN Standards*".

Question 2: MATLAB Simulations:

Jakes Fading Simulator Model Code: rayleigh_chan.m

```
function h=rayleigh_chan(C_samples, Fdmax, N, hindex)
%%The above function simulates the multipath Rayleigh Fading channel using the
%%Jakes's Fading model. It generates a normalised channel response h(t)
%%such that its average power is 1 for simplicity of comparison. The
%%simulator generates C_samples of channel samples at the nomralised
%%Doppler frequency Fdmax, to generate N multipath signals.

%% Jake's fading Simulator
M=0.5*(0.5*N-1);         %Number of oscillators required to generate N signals
n=1:M;
H=hadamard(M);           %Hadamard Matrix for increasing independence between
multipaths
theta=2*pi*n/N;
fd=Fdmax*cos(theta);     %Doppler Frequency - Normalised
bn=pi*n/(M+1);
gn=(2*pi*(M+1)*n)/(M+1);
A=H(hindex,:);

for index=1:C_samples
    %Channel Response
    h_t(index)=abs(sum(A.*cos(2*pi*fd*index+gn)*(cos(bn)+sin(bn)*1i)'));
end
Pavg=sum(h_t.^2)/(C_samples);    %Average Energy
h=h_t/sqrt(Pavg);                %Normalised Channel Response
```

Transceiver Simulation Code: main.m (for Mr=1 and 2):

```
%% Transceiver Parameters:
Mt=2;                        %No. of Transmitters=2
T=2;                         %No. of Time Slots=2
```

```
n=10^5;                     %Number of bits to be transferred
rhodB=1:20;                 %SNR Range in dB
rho=10.^(0.1.*rhodB);       %SNR Randge

%% Codeword Parameters (Cyclic STBC):
u1=1;                       %Optimized value for u1
u2=1;                       %Optimized value for u1
l=0:((Mt*T)-1);
L=Mt*T;                     %No. of Codewords
theta=2*pi/L;
V=[(exp(1j*u1*theta)) 0; 0 (exp(1j*u2*theta))]; %Generator Matrix for Cyclic STBC
(C1, codeword corresponding to l=1)

%% Message to be transferred for the MIMO simulation:
msg=randi([0 max(l)], n, 1);

%% Channel attributes (For Doppler effect consideration):
speedMPH=60;              %speed in miles per hour
speed=speedMPH*0.44704;   %speed conversion to m/sec, 1 miles/hour = 0.44704 m/sec
fc= 900e6 ;               %carrier frequency= 900Mhz
B= 30e3;                  %Bandwidth=30kHz
Rs= B;                    %Symbol Rate for Normalisation
c=3e8;                    %speed of light
N=34;                     %Number of Signals
C_samples=n;              %Channel Samples

%% Calculation of Maximum Doppler frequency & normalised Doppler
frequency=fdmax*Ts:
wavlen=c/fc;
fdmax=speed/wavlen;       %Maximum Doppler Frequency
Fdmax=fdmax/Rs;           %Normalise Doppler Frequency

%% Flat Fading Channel Response using Jakes Simulator (4 Independent Channels):
for hi=1:L
    h(hi,:)=rayleigh_chan(C_samples, Fdmax, N, hi);
end
hdB=10*log10(h);

%% Channel Response Plot for the first 400 samples:
figure(1);
t=1:400;
plot(t, hdB(1, 1:400), t, hdB(2, 1:400), t, hdB(3, 1:400), t, hdB(4, 1:400));
grid on;
legend('Channel 1','Channel 2','Channel 3','Channel 4');
title('Flat Fading Channel Response (400 Samples)');
xlabel('Number of Samples');
ylabel('Channel Amplitude |h(t)| in dB');

%Initializations:
p_err=zeros(2, length(rhodB));    %Simulated probability of error
recmsg=zeros(n,1);                %Received Message(Decoded)
distance=zeros(1,L);

%% Transmission and Reception for different SNR values, for different number of
receivers:
```

```
for Mr=1:2
    for index=1:length(rhodB)
        S=sqrt(Mt)*eye(Mt);      %Differential space time Code, ?=0
        Y=ones(T, Mr);           %Received Signal matrix corressponding to msg

        %% Transmission of message signal using Differential ST scheme:
        for i=2:n+1
            %Mapping of information bits to corressponding codewords Cl:
            in=msg(i-1);
            Cl=sqrt(Mt)*(V^(in));
            %Differential ST Coding:
            S=(1/sqrt(Mt))*Cl*S;
            %Flat fading channel response:
            H=h(1:(Mt*Mr),i-1);
            H=reshape(H,Mt,Mr);
            %AWGN ~ CN(0,1):
            var=1;
            Noise=sqrt(var)*randn(Mt,Mr) + sqrt(var)*1j*randn(Mt,Mr);
            %Received Signal at the Receiver for the 2 Time Slots:
            y=sqrt(rho(index)/Mt)*(S*H)+Noise;
            Y=horzcat(Y,y);
        end

        %% Maximum likelihood Detection of the received codeword:
        for j=Mr+1:Mr:Mr*(n+1)
          yt=Y(:,j:j+Mr-1);      %Received signal for time ?
          yt_1=Y(:,j-Mr:j-1);    %Received signal for time ?-1
          for k=1:length(l)
             Cd=sqrt(Mt)*(V^(k-1));
             dist= yt-((1/sqrt(Mt))*Cd*yt_1);
             distance(k)=(norm(dist,'fro'))^2; %Maximum Likelihood detection for
differential ST scheme
          end
          recmsg((j-1)/Mr)=find(distance==min(distance))-1;
        end

    %Experimental SER Computation from the Simulation:
    no_errors=length(find(msg~=recmsg));
    p_err(Mr,index)=no_errors/n;
    end
end

%% Plot of Symbol Error Rate as a function of SNR:
figure(2);
semilogy(rhodB, p_err(1,:),rhodB, p_err(2,:));
grid on;
legend('Mr=1','Mr=2');
title('SER vs. SNR curve for Differential codes');
xlabel('SNR(dB)');
ylabel('Symbol Error Rate (SER)');
```

Output:

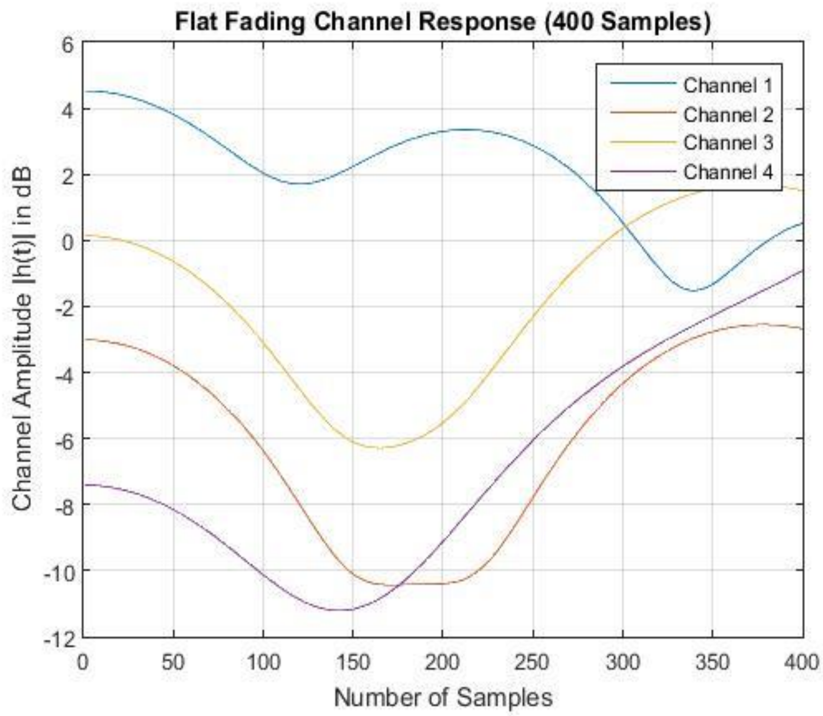

Figure 2: 400 Samples of Channel Coefficients

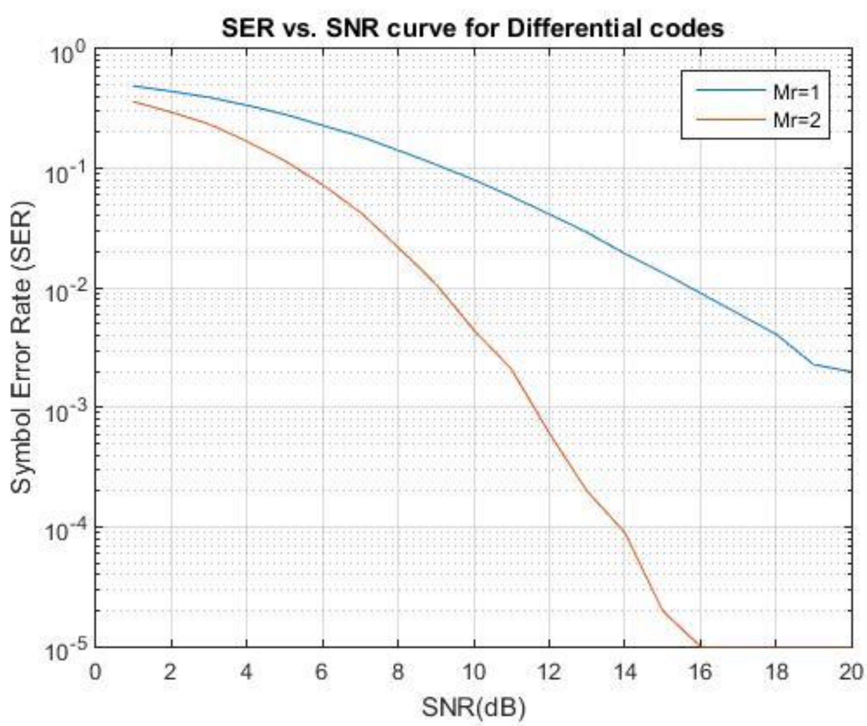

Figure 3: SER curve as a function of SNR for different Mr

Observation:

1. It is observed that the probability of error decreases as the SNR increases.
2. The rate of decrease in probability of error increases as the number of receivers is increased.

Inference:

1. Increasing the SNR, decreases the effect of the Gaussian noise, and the receiver can make a better estimation of the received message.
2. Increasing the number of receivers, increases the slope of the PEP (P_e) as shown below,

$$\log_{10} P_e \leq -rM_r \log_{10}\frac{\rho}{4M_t} - M_r \log_{10}\prod_{i=1}^{r}\lambda_i$$

It can be seen that the slope of the equation above is given by $-rM_r$ indicating that the number of receivers (M_r) affect the slope of the PEP curve, hence the rate of decrease of probability of error with increase with an increase M_r. There for $M_r = 2$, probability of error falls sharply as compared to $M_r = 1$.