Design and Implementation of Efficient Codes for MIMO Wireless Telecommunication Systems

Hamad El Gibreen, Awadh Abu-Fahesh, Ahmad Al-Issa & Saeed Al-Shehri

MOTIVATION

Why this Project ?

- The main objective of this project is to linearly simplify the algorithms of general Matlab functions which have been used for MIMO systems

Why do we need to bother simplifying these functions when the simulation is already working?

- **Implementable code**
to have the final product easily implemented on hardware of the available MIMO system in the department.
- **2x2/4x4 optimization**
it was decided to make the simplification optimized mainly for 2x2 and 4x4 systems; this was due to the lack of time available to do it for all scenarios in addition to the similarity of 2x2/4x4 MIMO to real life situations (4G LTE, WiFi, etc…).
- **Less memory and processing consumption**
With the developed simplification, implementing it for the available hardware as well as expanding it for other –more complex- systems will save a lot of processing time and power. Also, the consumption of memory (RAM and ROM) in the hardware is also remarkably reduced

MECHANISMS

This project was mainly on 4x4 MIMO systems, and it was mainly focused on:

- Linear simplification of Zero Forcing (ZF) algorithms for 2x2 and 4x4 MIMO systems.
- Linear simplification of V-BLAST (ZF-SIC) **without** optimal ordering algorithms for 4x4 MIMO systems.
- Linear simplification of V-BLAST (ZF-SIC) **with** optimal ordering algorithms for 4x4 MIMO systems.
- Performance comparisons between the developed simplifications and the original code, in addition to performance comparisons between the different simplified techniques.

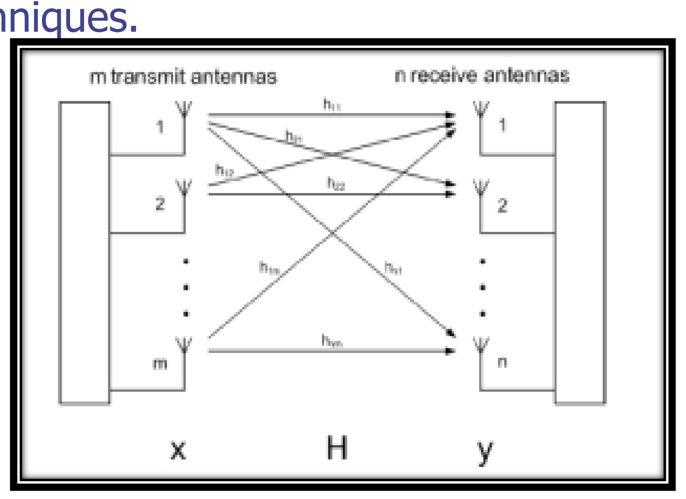

Figure1: General MIMO System Diagram

METHODOLOGY

"Zero Forcing Only" Simplification:

The received signal in a MIMO system is represented by: $y = Hx + n$

To solve for x , we know that we need to find a matrix which satisfies WH= I . The Zero Forcing (ZF) linear detector for meeting this constraint is given by:

$$W = (H^H H)^{-1} H^H$$

So, since we were primarily focusing on 2x2/4x4 implementation, we came up with different methods to simplify this equation

- Using Regular Inverse for 2x2 and 4x4 ZF MIMO:
Here, and since we are working with equal rows/columns matrices, we decided to start out by replacing the generalized inverse with regular inverse

- Using Linear Simplification for 2x2 ZF MIMO:
for us to extract the transmitted symbol ***x*** ,we multiply by the inverse of ***h*** $H^{-1}y = x + H^{-1}n$
Which, for 2x2 systems, will be equivalently:

$$\frac{1}{\det H}\begin{bmatrix} h2,2 & -h1,2 \\ -h2,1 & h1,1 \end{bmatrix}\begin{bmatrix} y1 \\ y2 \end{bmatrix} = \begin{bmatrix} x1 \\ x2 \end{bmatrix} + \frac{1}{\det H}\begin{bmatrix} h2,2 & -h1,2 \\ -h2,1 & h1,1 \end{bmatrix}\begin{bmatrix} n1 \\ n2 \end{bmatrix}$$

Converting it into linear equations instead of matrix format, along with ignoring the noise:

$$x1 = \frac{1}{\det H} \times (h2,2 \times y1 - h1,2 \times y2)$$ and $$x2 = \frac{1}{\det H} \times (-h2,1 \times y1 + h1,1 \times y2)$$

- **Using Linear Simplifications for 4x4 ZF MIMO**:
This linear simplification can be expanded for 4x4 matrices, we used the regular (linear) concept to find the inverse; which can be generally derived as the following:

For a 4x4 matrix A and the inverse matrix of **A** are

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \qquad \mathbf{A}^{-1} = \frac{1}{\det \mathbf{A}} \begin{pmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{pmatrix}$$

Zero Forcing With Successive Interference Cancellation:

- *ZF-SIC without ordering simplifications for 4x4 MIMO:*
ZF-SIC is an expansion of regular ZF equalizer. So, when looking into the original code of it there are minor improvements over the "ZF Only" one. The original code is shown below.

- ZF-SIC With Ordering Simplifications for 4x4 MIMO:
Using this method, we can find out the transmit symbol (after multiplication with the channel) which came at higher power at the receiver. Therefore, there are slight differences between this approach and the previous one.

```
function
BE=ZFBLASTNoOrder(r,H,SignalSet,Modulation,Input,
BitMapping,SimType)

%%% V-Blast Detector With ZF without Ordering

global NTx MRx qset

G=ZFInvers(H);

HH=H;

for ii=1:NTx %%%%% try to convert this into
linear equations

    w=G(1,:);

    y=w*r;   %% Interfernce Nulling

    a(ii)=Detector(y,SignalSet,1);  %% detection

    r=r-H(:,ii)*SignalSet(a(ii)); %%Interfernece
Cancellation

    HH(:,1)=[];

   % HH(:,1)=zeros(MRx,1);

    G=ZFInvers(HH);

end

BE=BECalculator(Input,a,BitMapping);%%% Calculat
the Bit Errors

switch SimType

case 1

    if BE>0

       BE=1; %FER counter

    end

case 2

end
```

Figure 2: original code of ZFBLASTNoOrder function

```
function
BE=ZFBLASTOrder(r,H,SignalSet,Modulation,Input,BitMapping,SimTy
pe)

%%% V-Blast Detector With ZF without Ordering

global NTx MRx qset

G=ZFInvers(H);

HH=H;

%kk=TrackOrder(G);%% kk will have the decoding order of V-Blast

BE=0;

for ii=1:NTx

    k(ii)=MinNorm(G);

    w=G(k(ii),:);

    y=w*r;   %% Interfernce Nulling

    a(ii)=Detector(y,SignalSet,1);  %% detection

    BE=BE+BECalculator(Input(k(ii)),a(ii),BitMapping);%%%
Calculat the Bit Errors

    switch SimType

    case 1

       if BE>0

          BE=1;

          return;

       end

    case 2

    end

    r=r-HH(:,k(ii))*SignalSet(a(ii)); %%Interfernece
Cancellation
```

Figure 3: orginial code of ZFBLAST with order function

```
    %HH(:,k)=zeros(MRx,1);
```

EXPERIMENTAL RESULTS

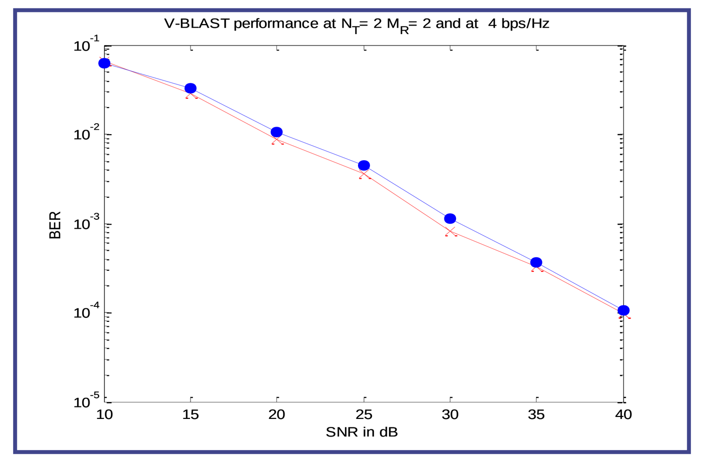

Fig. 4: Performance output of 2x2 MIMO System using ZF Only

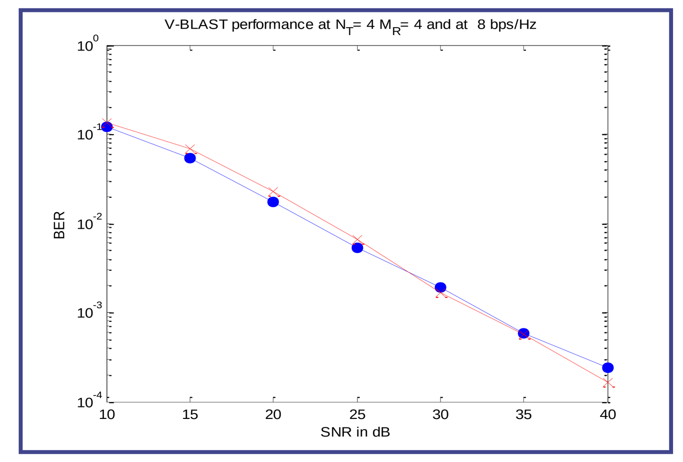

Fig. 5: Performance output of 4x4 MIMO System using ZF Only

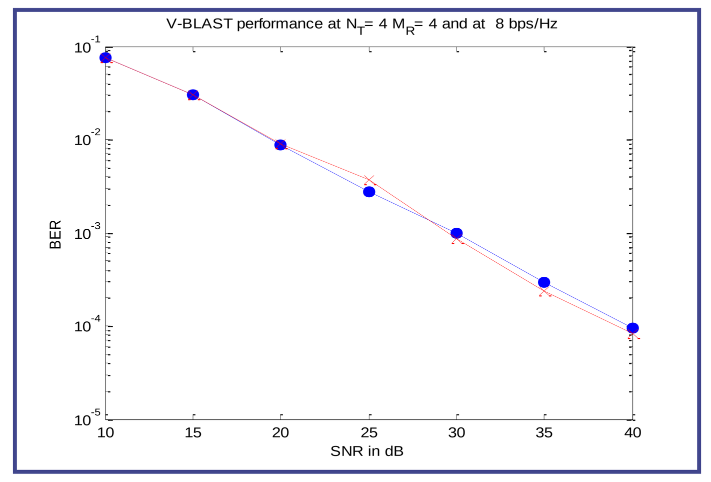

Fig. 6: Performance output of 4x4 MIMO System using ZF-SIC Without ordering

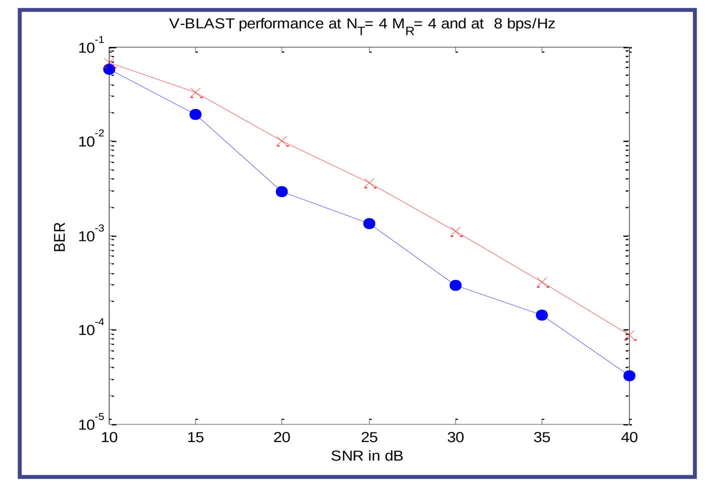

Fig. 7: Performance output of 4x4 MIMO System using ZF-SIC With ordering.

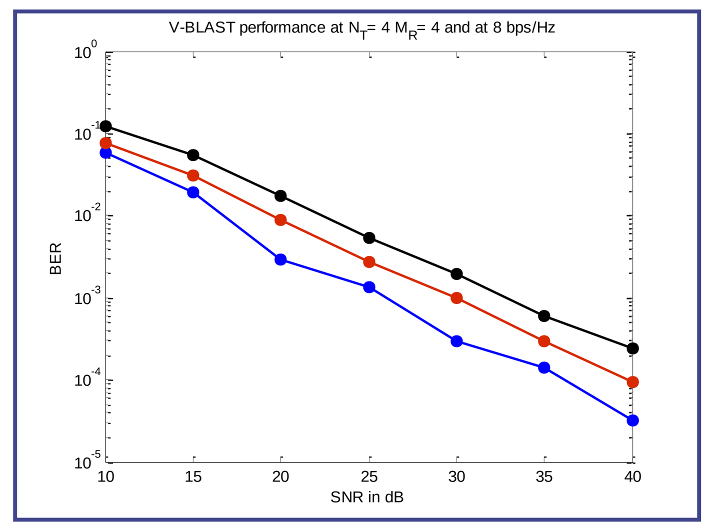

Fig.8: Performance output of 4x4 MIMO System using different signal detection schemes (original code)

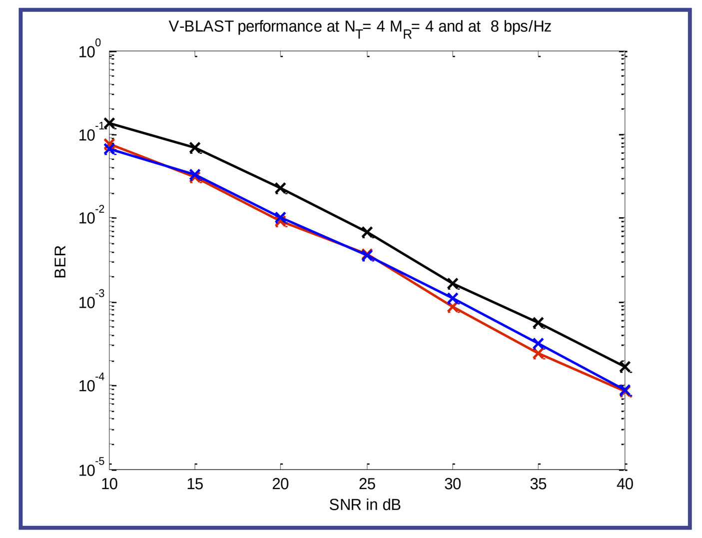

Fig.9: Performance of 4x4 MIMO System using different signal detection schemes (simplified code)

FUTURE WORK

- Inserting our simplified implementation code into the available MIMO hardware in the department successfully
- Simulating it in real time and compare these results to our simulated ones
- out that other scenarios can be simplified linearly for the available hardware implementation (1x4, 2x4, 3x4 MIMO and vice versa).