MIMO Systems: Non-Linear Equalisation — V-BLAST Detection

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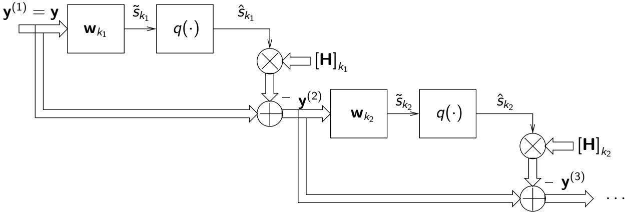
Adaptive DSP course for MSc & PhD students — Lecture no. 4

May 28, 2011

Overview

Vertical Bell-lab LAyered Space Time (V-BLAST)



- Motivated by the study of layered space-time architecture of a MIMO system in [1, 2], decoupling between distinct spatial modes can result in a system in which capacity increases linearly with $\min(N_t, N_r)$
- Consequently, V-BLAST architecture was proposed [3, 4, 5] to realise the capacity advantage promised on MIMO channels
- This architecture is, in fact, a layered detection scheme based on the DFE method in which a received data vector is detected on a symbol-by-symbol basis, i.e. layer-by-layer

V-BLAST (cont'd)

- The successive detection ordering of the V-BLAST is optimised in the sense of maximising the worst post-detected SNR [4]
- This leads to detecting weak layer components of the data vector more reliably. Indeed the overall detection performance is dominated by the signature of weak layers if the obvious order of antenna labelling is selected as in the case of the DFE system
- The optimum detection ordering strategy of the V-BLAST is shown to minimise the symbol error ratio (SER) by detecting at each iteration the component associated with the highest SNR [3], an approach that is known as "best first" [6]
- This can be viewed as a virtual relabelling of the transmit antennas. Detection proceeds by nulling out the interference of other layers in a successive manner which is a popular method of equalising interference and achieving parallel AWGN subchannels

V-BLAST Algorithm

The V-BLAST algorithm comprising of four main steps:

1. *Ordering*: determine the most reliable symbol component position (order) k_i according to the criterion in (c)
2. *Nulling*: compute its corresponding ZF or MMSE nulling vector $\mathbf{w}_{k_i}$ using (d), then obtain the decision statistic $\tilde{s}_{k_i}$ as in (e)
3. *Slicing*: or quantising to the nearest alphabet according to the used constellation as in (f)
4. *Cancellation*: subtracting out its interference contribution from the received vector $\mathbf{y}$ using (g)

The main computational bottleneck of the V-BLAST architecture lies in the repeated pseudo-inverse or normal inverse in the ordering step of both ZF and MMSE V-BLAST algorithms [7]

ZF V-BLAST

Initialisation:

a. $\mathbf{G}_{\mathrm{ZF}}^{(1)} = \mathbf{H}^{+} = \left[\mathbf{H}^{\mathrm{H}}\mathbf{H}\right]^{-1}\mathbf{H}^{\mathrm{H}}$

b. $i = 1$

Recursion:

c. $k_i = \underset{j \notin \{k_1,\ldots,k_{i-1}\}}{\mathrm{argmin}} \left\| \left(\mathbf{G}_{\mathrm{ZF}}^{(i)}\right)_j \right\|_2^2$

d. $\mathbf{w}_{k_i} = \left(\mathbf{G}_{\mathrm{ZF}}^{(i)}\right)_{k_i}$

e. $\tilde{s}_{k_i} = \mathbf{w}_{k_i}\mathbf{y}^{(i)}$

f. $\hat{s}_{k_i} = q\left(\tilde{s}_{k_i}\right)$

g. $\mathbf{y}^{(i+1)} = \mathbf{y}^{(i)} - \hat{s}_{k_i}\left[\mathbf{H}\right]_{k_i}$

h. $\mathbf{G}_{\mathrm{ZF}}^{(i+1)} = \mathbf{H}_{\overline{k_i}}^{+}$

i. $i = i + 1$

MMSE V-BLAST

Initialisation:

a. Compute $\mathbf{D}^{(1)}$ and then $\mathbf{G}^{(1)}_{\mathrm{MMSE}}$ using (1) and (2), respectively

b. $i = 1$

Recursion:

c. $k_i = \underset{j \notin \{k_1, \ldots, k_{i-1}\}}{\operatorname{argmin}} \mathbf{D}^{(i)}_j$

d. $\mathbf{w}_{k_i} = \left(\mathbf{G}^{(i)}_{\mathrm{MMSE}}\right)_{k_i}$

e. $\tilde{s}_{k_i} = \mathbf{w}_{k_i} \mathbf{y}^{(i)}$

f. $\hat{s}_{k_i} = q\left(\tilde{s}_{k_i}\right)$

g. $\mathbf{y}^{(i+1)} = \mathbf{y}^{(i)} - \hat{s}_{k_i} [\mathbf{H}]_{k_i}$

h. $[\mathbf{H}]_{k_i} = \mathbf{0}_{N_r \times 1}$

i. Compute $\mathbf{D}^{(i)}$ then $\mathbf{G}^{(i)}_{\mathrm{MMSE}}$ using (1) and (2), respectively

j. $i = i + 1$

V-BLAST Algorithm (cont'd)

Finally, the updates (h)-(j) are required to proceed with the next component. Note that the difference between ZF and MMSE V-BLAST algorithms as listed in above lies only in computing the position of the highest SNR symbol component in (c). For ZF this is achieved by obtaining the minimum row-norm of **G**, while for MMSE this is associated with the smallest diagonal entry [8] of

$$\mathbf{D} = \left[\mathbf{H}^{\mathrm{H}}\mathbf{H} + \xi \mathbf{I}_{N_t}\right]^{-1}, \quad (1)$$

with the MMSE filter given by

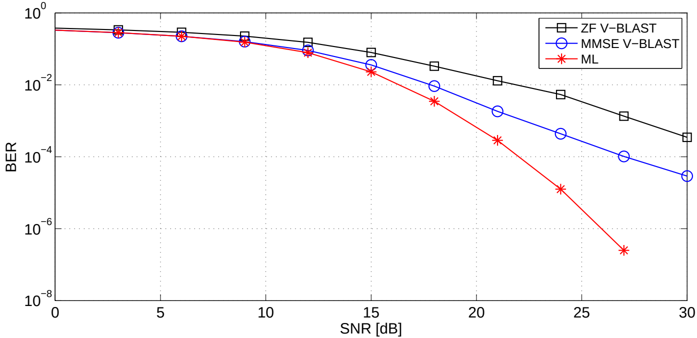
$$\mathbf{G}_{\mathrm{MMSE}} = \mathbf{D}\mathbf{H}^{\mathrm{H}}, \quad (2)$$

where ξ is the reciprocal of the SNR. As in linear filter systems, the detection performance of the V-BLAST under the MMSE criterion outperforms the ZF one.

Note that $\mathbf{H}_{\underline{k_i}}^{+}$ in step (h) of the ZF V-BLAST algorithm denotes the pseudo-inverse of **H** after zeroing the columns $k_1, k_2, \cdots, k_i$

Results

BER performance of V-BLAST ZF and MMSE against ML detection for a 4×4 MIMO system with 4-QAM modulation averaged over 300 realisations of a channel matrix normalised such that $\|\mathbf{H}\|_F = 1$. Advantages of more than 5 dB at $\mathrm{BER} = 10^{-3}$ gained by V-BLAST MMSE detection over its ZF counterpart while less than 3 dB is lost compared to the ML detection



Conclusion

Concluding remarks

- V-BLAST detection algorithm as a non-linear equalisation technique is studied to obtain better performance compared to linear methods
- Both ZF and MMSE criterion of V-BLAST algorithm are introduced
- V-BLAST detection is basically a DFE system with optimum detection ordering. In other words, if the obvious antenna labelling order is followed, V-BLAST algorithm will reduced to the DFE system
- Simulation results are provided to compare between V-BLAST algorithms and MLD

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