VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY

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MOBILE & PORTABLE RADIO RESEARCH GROUP

# Outage Capacity Comparison of Multi-Layered STBC and V-BLAST Systems


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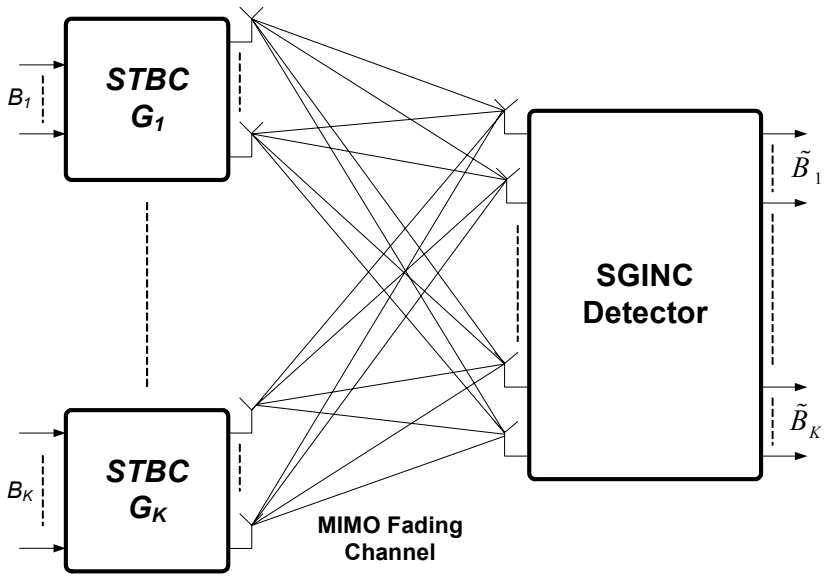
# Outline

- System Description
  - Architecture and Model
- Outage Capacity
  - V-BLAST and STBC
  - MLSTBC
- Simulation Results

# Multi-layered STBC is a single user system that consists of *K* parallel STBC

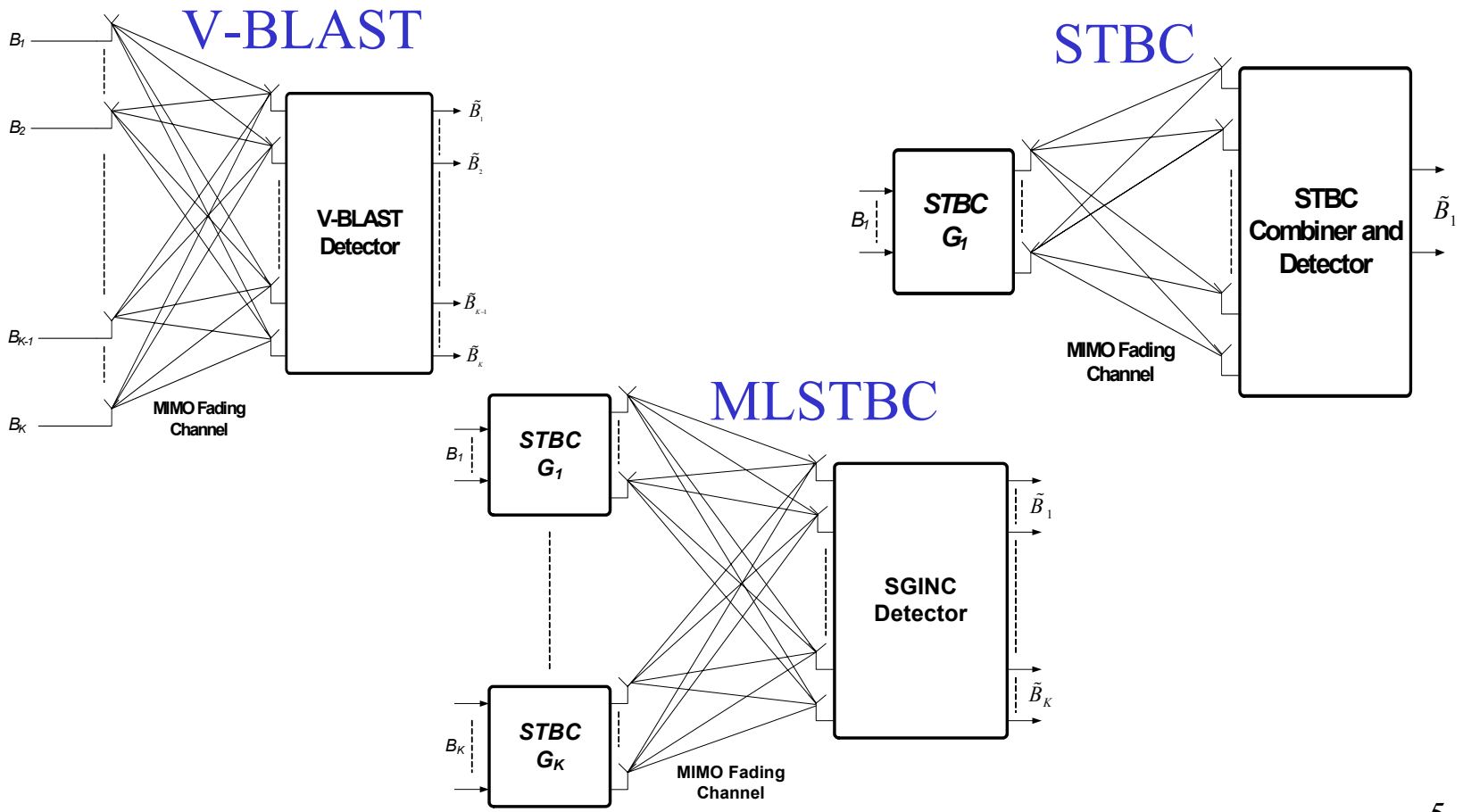
- It combines spatial multiplexing with transmit diversity.
- It is a V-BLAST system with STBC on each layer.



# Literature

- Literature review:
  - Multilayered STTC [Tarokh, et al. 1998]
  - Detection algorithms comparison for MLSTBC [Mohammad, et al. 2004]
  - MLSTBC for MIMO-OFDM systems [Al-Ghadhban, et al. 2004]
- So, what is the advantage of MLSTBC and how does it compare to other MIMO systems?

The study compares the information capacity of MLSTBC to open loop MIMO systems such as V-BLAST and STBC.

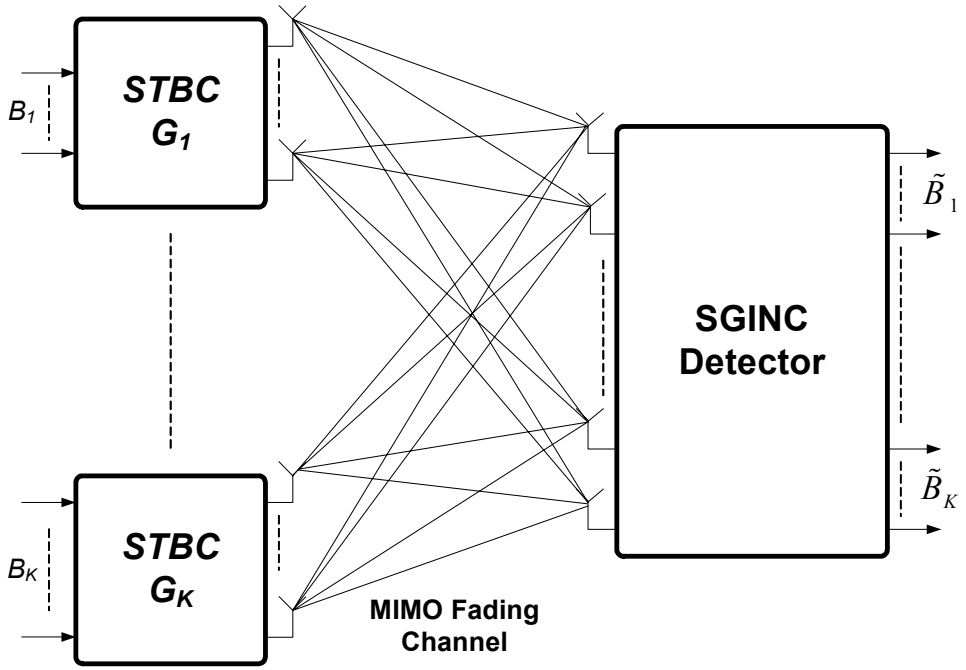


# The discrete received signal over *T* time slots is

*M*: total number of receive antennas
$N_G$: number of transmit antennas per group
*N*: total number of transmit antennas

$$\mathbf{Y} = \mathbf{HS} + \mathbf{V}$$

$$= \begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 & \cdots & \mathbf{H}_K \end{bmatrix} \begin{bmatrix} \mathbf{S}_1 \\ \mathbf{S}_2 \\ \vdots \\ \mathbf{S}_K \end{bmatrix} + \mathbf{V}$$

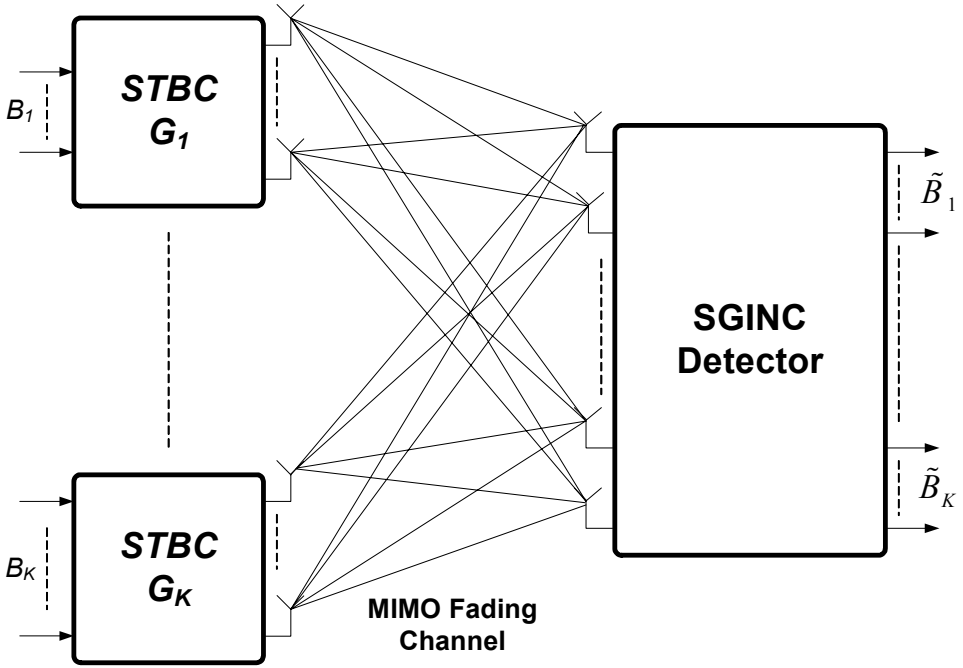



$\mathbf{S}_i$ is the *i*th STBC.
$\mathbf{H}_i$ is the $M \times N_G$ MIMO matrix from group *i* to the receiver.

# Due to the short code length of STBC, the received signals over *T* slots are rearranged into a vector

$$\mathbf{y} = \hat{\mathbf{H}}\mathbf{x} + \boldsymbol{\eta}$$

$$= \begin{bmatrix} \hat{\mathbf{H}}_1 & \hat{\mathbf{H}}_2 & \cdots & \hat{\mathbf{H}}_K \end{bmatrix} \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_K \end{bmatrix} + \boldsymbol{\eta}$$




$\mathbf{x}_i$ is the symbols of the *i*th layer.

$\hat{\mathbf{H}}_i$ is the $M \cdot T \times N_G$ MIMO matrix from group *i* to the receiver.

# Serial Group Interference Nulling and Cancellation (SGINC)

- *Group interference nulling*: Based on an ordering criterion, assume that the first detected group is the $i^{th}$ group. Then, the algorithm calculates the orthonormal bases of the null space of:

$$H_i = \left[ \hat{\mathbf{H}}_1 \quad \cdots \quad \hat{\mathbf{H}}_{i-1} \quad \hat{\mathbf{H}}_{i+1} \quad \cdots \quad \hat{\mathbf{H}}_K \right]$$

- Denote the orthonormal bases of the null space of $\mathrm{H}_i$ by $N_i$ , then the received signal for the $i^{th}$ group after nulling is:

$$\tilde{\mathbf{y}}_i = N_i \mathbf{y} = \tilde{\mathbf{H}}_i \mathbf{x}_i + \tilde{\boldsymbol{\eta}}_i$$

Where $\tilde{\mathbf{H}}_i$ is the post-processing channel matrix.

# SGINC

- *STBC Combiner:* $\tilde{\mathbf{x}}_i = \tilde{\mathbf{H}}_i^H \tilde{\mathbf{y}}_i$
- *Group interference cancellation*: After detecting the $i^{th}$ group, its contribution is subtracted from the received signal and the processing is repeated serially for each group.
- *Ordering* is based on the Frobenius norm (FN) of $\tilde{\mathbf{H}}_i$ , the layer with the maximum FN is detected first.
- Number of receive antennas should be greater than or equal to number of layers.

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# Outage Capacity

- V-BLAST [Papadias and Foschini 2002]:

$$C_{VBLAST}^{ZF} = K \cdot \min_{i=1,2,\ldots,K} \left\{ \log_2 \left( 1 + \frac{\rho}{K \left\| \mathrm{W}_{ZF,i} \right\|^2} \right) \right\}$$

- STBC [Sandhu and Paulraj 2000]:

$$C_{STBC} = r_c \log_2 \left( 1 + \frac{\rho}{N_G} \left\| \mathbf{H} \right\|_F^2 \right)$$

# MLSTBC Outage Capacity

- Since MLSTBC is a single user system and the transmitter doesn't know the channel and all groups transmit at the same rate, an outage will occur if an outage happens in one layer "the weakest". Therefore, the instantaneous capacity of a *K* group STBC system is:

$$C_{MLSTBC}^{GNIC} = K \cdot \min_{i=1,2,\ldots,K} \left\{ r_c \log_2 \left( 1 + \frac{\rho}{K \cdot N_G} \left( \frac{\left\| \tilde{\mathbf{H}}_i \right\|_F^2}{T} \right) \right) \right\}$$

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# Comparative Study

- Complementary cumulative distribution function (CCDF)
- Spectral efficiency
- Outage probability
- Layers – capacity tradeoffs

# Simulation Setup

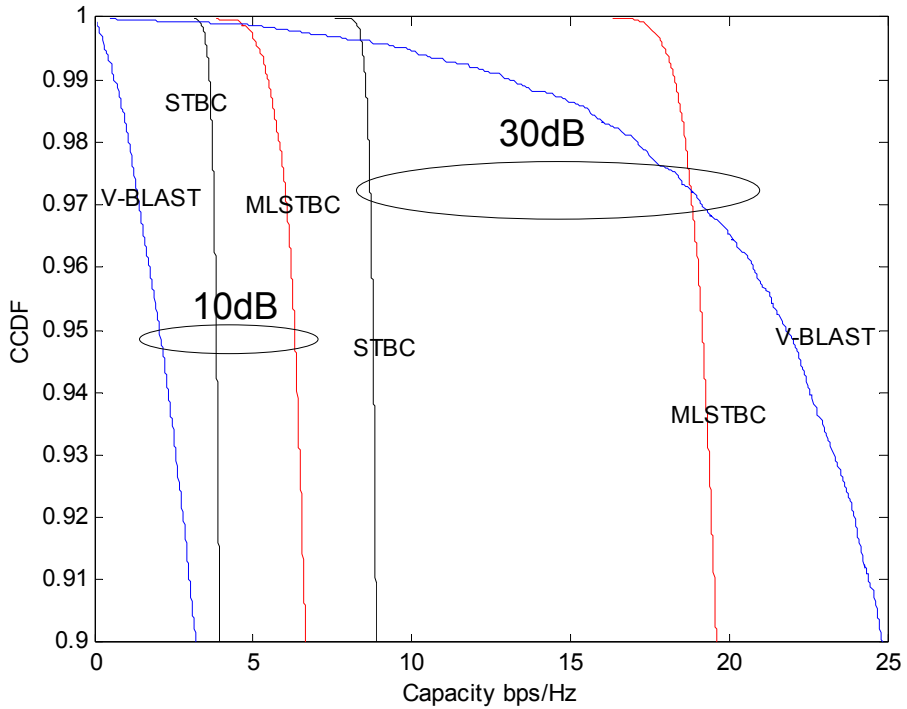
- Each STBC in the multi-layered system is Alamouti's full-rate full-rank code with two transmit antennas.
- STBC used for four transmit antennas is full-rank orthogonal code of rate ¾.
- The capacity of the different systems is estimated by generating random complex Gaussian channel realizations from which the instantaneous capacity is calculated and then the capacity probability distribution function (pdf) is approximated.

# The key difference between MLSTBC and V-BLAST at same number of antennas is

- MLSTBC has more spatial diversity while V-BLAST has more layers.
- For 4×4 MIMO system, MLSTBC has two layers and each layer has a transmit diversity of two. At the receiver, the first detected layer has a receive diversity of three since it needs one antenna to null out one interfering layer and the rest provide diversity.
- On the other hand, V-BLAST has four layers and no transmit diversity. In addition, the first detected layer has no receive diversity because the algorithm needs three antennas to null out three interfering layers.

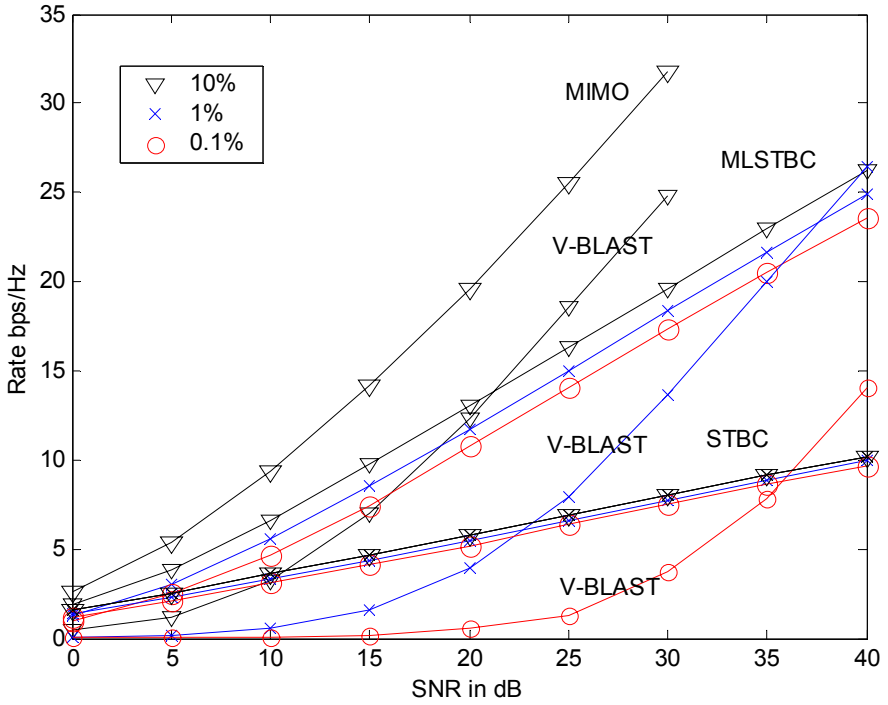
# CCDF at 4×4 MIMO Channels

At low outage probabilities, MLSTBC supports more capacity than V-BLAST and STBC.



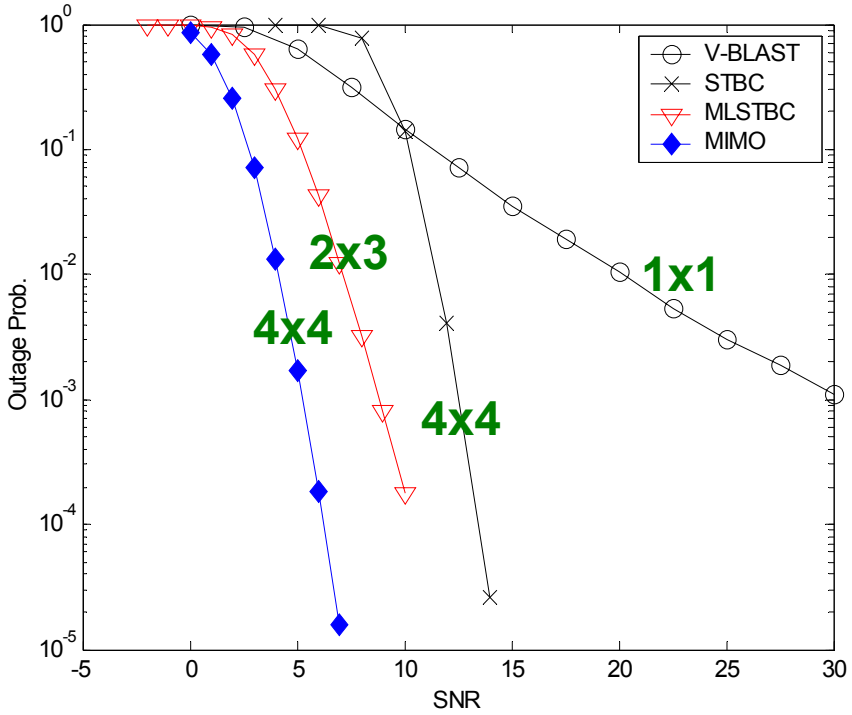
# Spectral Efficiency at 4×4 MIMO Channels

- V-BLAST spatial multiplexing gain is parallel to optimal MIMO at high SNR
- Although, MLSTBC has slower rate of increase in spectral efficiency, it supports more rate at low and moderate SNR and at low outages.

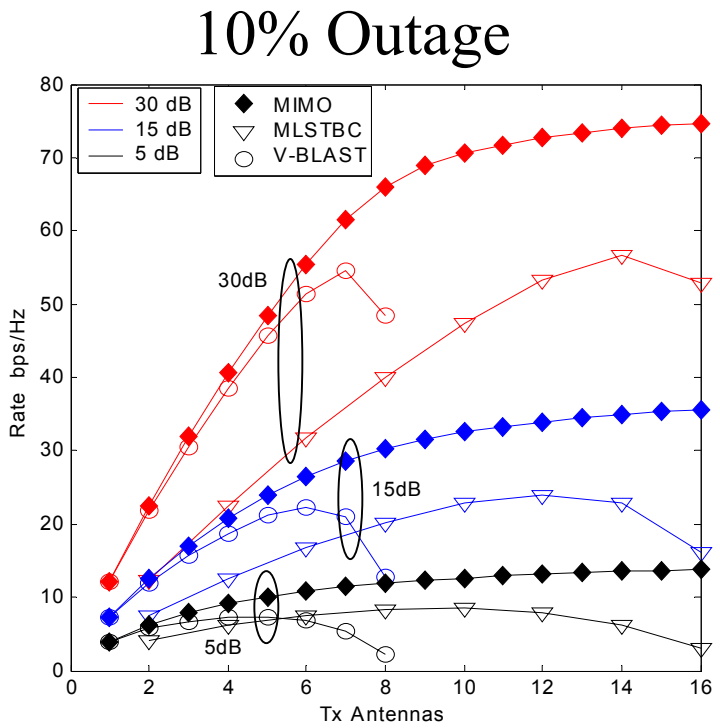


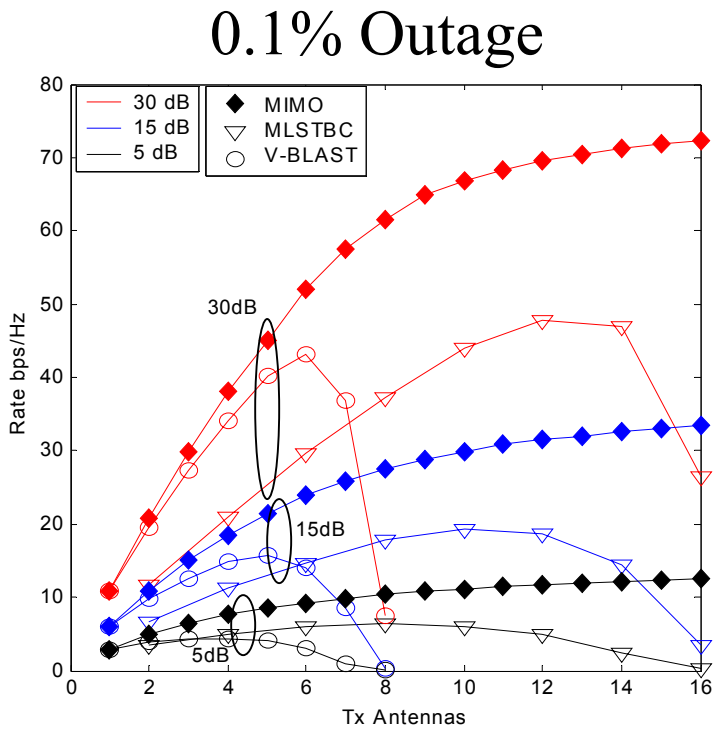
# Outage Probability at 4 bps/Hz and over 4×4 MIMO Channels

- MLSTBC is more power efficient than V-BLAST and STBC.
- 5dB far from optimal MIMO at $10^{-4}$ outage.



# Number of layers Effect on the Capacity at Eight Receive Antennas



# Conclusions

- When the number of transmit and receive antennas is equal, MLSTBC is more power efficient and it is more spectral efficient at low SNR and low outage probabilities.
- Due to the nulling operation in the detection algorithms of V-BLAST and MLSTBC, there is a capacity reduction after adding certain number of layers. So operating at full spatial multiplexing doesn’t achieve the highest capacity.