Large Antenna Array for Low-Latency and Ultra-Reliable Communication

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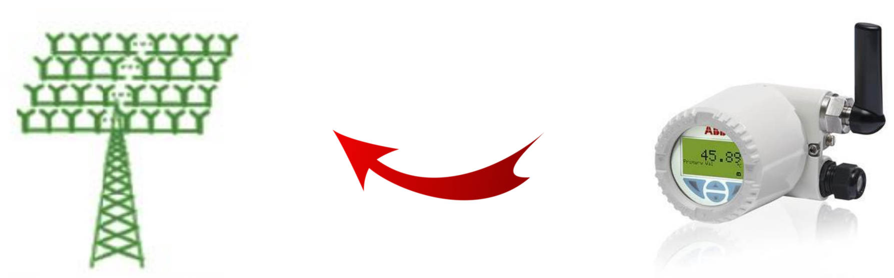


Scenario under investigation

- **Highly reliable** (99.999%, BLER 10^{-9})
- **Low latency** (<1ms end to end)
- **Low power** (2-5 years battery life)
- **Large number of connected sensors and actuators** (≈300 devices per 10x10x3 cube meter area)
- **Exchanging short data packets sporadically** (≈16 Byte on air interface)
- **Channel capacity** (not much of a concern)
- **Suitable for Industrial automation and safety application**

System Model

$$Y_k = \sqrt{\frac{\rho}{M}} X_k H_k + W_k$$

Y_k is a $T \times N$ complex matrix of the received signal

X_k is a $T \times M$ complex matrix of the transmitted signal

H_k is a $M \times N$ channel matrix

W_k is a $T \times N$ matrix of AWGN and the distribution for each element is $\mathcal{CN}(0,1)$

$$H_k = R_t^{1/2} H_{w,k} R_r^{1/2}$$

R_t is the $M \times M$ transmit covariance matrix

R_r is the $N \times N$ receive covariance matrix.

$H_{w,k}$ is an IID $M \times N$ channel matrix and the distribution for each element is $\mathcal{CN}(0,1)$

Antenna Correlation

$$R_t = \begin{bmatrix} 1 & r_t \\ r_t & 1 \end{bmatrix},$$

$$R_r = \begin{bmatrix} 1 & r_r & r_r^2 & r_r^3 & \cdots & \cdots \\ r_r & 1 & r_r & r_r^2 & \cdots & \cdots \\ r_r^2 & r_r & 1 & r_r & \cdots & \cdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \cdots & \cdots & \cdots & r_r^2 & r_r & 1 \end{bmatrix}$$

No Antenna Co-relation: $r_r = 0$ or $r_t = 0$

With Antenna Co-relation: $r_r = 0.9$ or $r_t = 0.9$

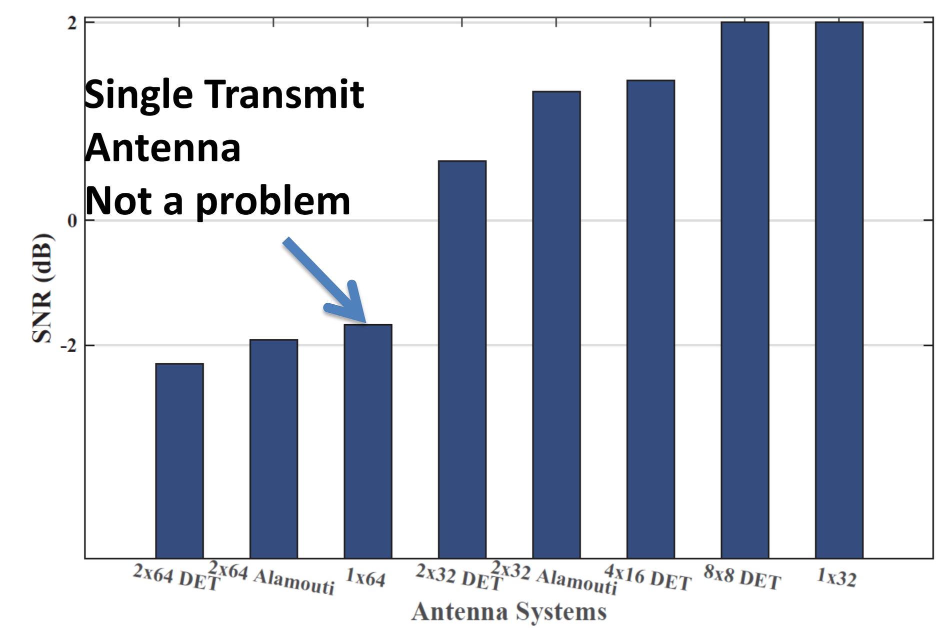
Conclusion

- **Single Antenna at the sensor is not a limiting factor.**
- **Antenna correlation does not have always a negative impacts on diversity performance, unlike smaller antenna arrays.**
- **Non coherent MIMO receiver with large antenna arrays can achieve desired latency and reliability requirements.**

Reference

- Panigrahi, Smruti Ranjan, Niclas Bjorsell, and Mats Bengtsson. "Feasibility of large antenna arrays towards low latency ultra reliable communication." Industrial Technology (ICIT), 2017 IEEE International Conference on. IEEE, 2017.
- D. Paulraj, Arogyaswami and Nabar, Rohit and Gore, Introduction to space-time wireless communications. Cambridge university press, 2003..
- J. R. Hampton, Introduction to MIMO Communications. Cambridge: Cambridge University Press, 2013.
- I. Kammoun, A. M. Cipriano, and J.-C. Belfiore, "Non-Coherent Codes over the Grassmannian," IEEE Transactions on Wireless Communications, vol. 6, no. 10, pp. 3657–3667, oct 2007.

SNR requirement to achieve 10^{-9} SER (QPSK modulation)

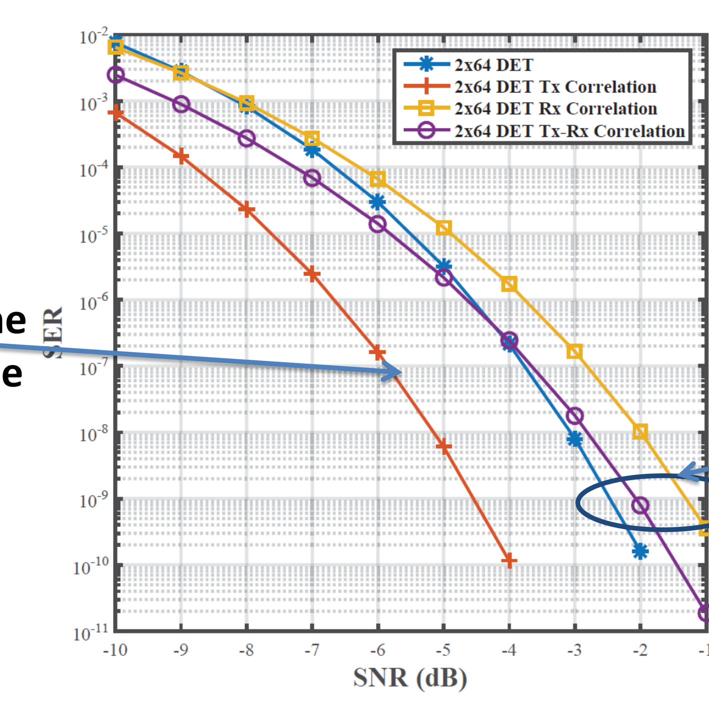


Scenario-1: channel known to the transmitter

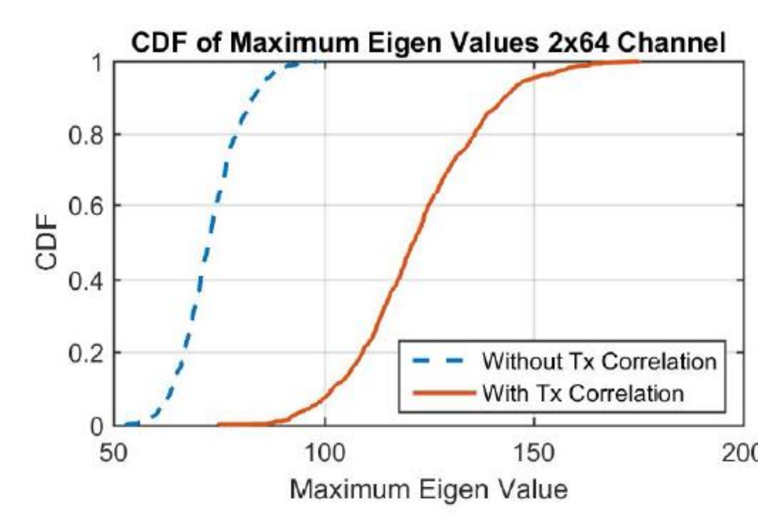
Dominant Eigen mode Technique: Not a good option for low latency communication

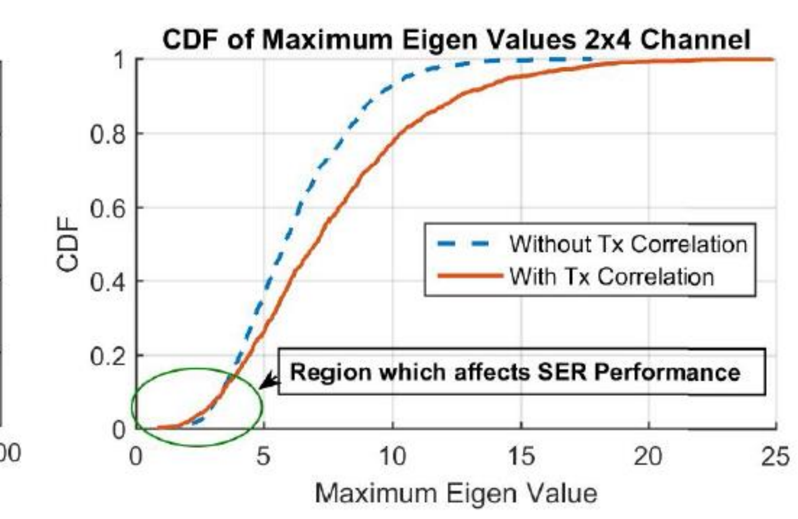
Tx Antenna Correlation increases the performance

Why?



Rx Antenna Correlation not so bad



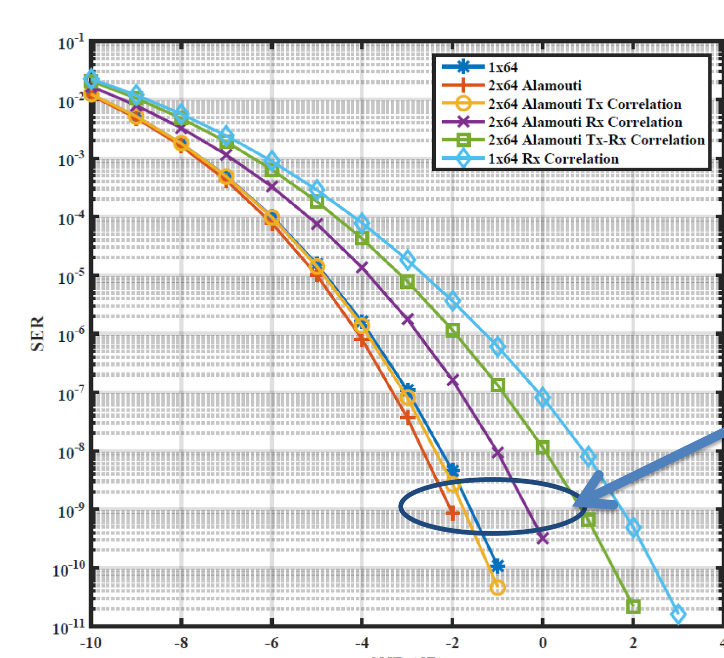


Effective received signal, $z = \sqrt{\rho \lambda_{\max}} x + w$, where $\lambda_{\max}$ is the maximum eigenvalue of $H_k^* H_k$.

The corresponding SNR at the receiver is $\eta = \lambda_{\max} \rho$

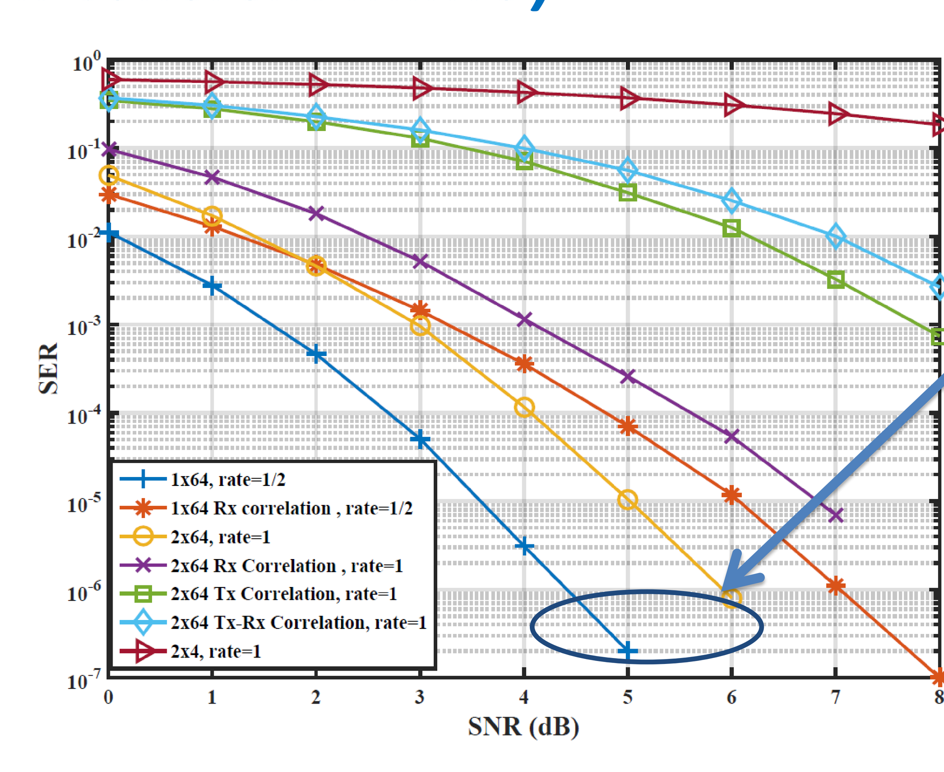
$$P_e \approx \bar{N}_e Q\left(\sqrt{\frac{\eta d_{\min}^2}{2}}\right)$$

Scenario-2: channel unknown to the transmitter



- 1x64 and 2x64 identical performance
- Rx Antenna Correlation performance not so bad

Scenario-3: channel unknown to both the transmitter and receiver (Non-coherent MIMO)



SNR requirement is fairly reasonable