A Stroll with Shannon to Next-Generation Plaza:
Large-Scale MIMOs, Single versus Multiple RF Chains and All That...

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• The History...

A Stroll with Shannon to Next-Generation Plaza...
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- **The Myth**: 'flawless tele-presence' with zero error for anyone, anywhere, anytime...

- **The Reality...**


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**Shannon’s Lesson # 1 -** \( B \): Bandwidth

**mm-Wave & Optical Wireless**

\[
C = M \cdot B / N_f \cdot \log(1 + SINR)
\]

1. Shannon’s Lesson # 1 \( B \): Bandwidth - mm-Wave & Optical Wireless

2. Shannon’s Lesson # 2 \( N_f \): Frequency-reuse factor - Small Cells, HetNets, FFR & all that...

3. Shannon’s Lesson # 3 \( SINR \): No. of RX antennas (N) - Large-Scale MIMOs for RX-diversity, Beamforming & Interference Alignment

4. Shannon’s Lesson # 4 \( M \): No. of TX antennas - Large-scale MIMOs for BLAST and Spatial Modulation


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**Figure 1:** Channel capacity upper bound of LTE-style near-instantaneously adaptive QAM (AQAM) and fixed modulation schemes over the dispersive TU Rayleigh Fading channel for BER=1% and BER=0.01%.
Figure 2: Pathloss versus carrier frequency, portraying the typical oxygen and water vapour absorption phenomena © Steele & Hanzo, 1999

But do you think Dr Shannon...?
Would the field of wireless have developed equally bandwidth-consciously, if...?

What if governments had not imposed frequency-licence fees...?

What about 'Green Radio'...?

What about the 'Tactile Internet'...?

Massive Optical-Wireless MIMOs & Li-Fi...

- [http://www.vlcc.net/?ml_lang=en](http://www.vlcc.net/?ml_lang=en)
- [http://www.lificonsortium.org/index.html](http://www.lificonsortium.org/index.html)

Shannon’s Lesson # 2 - $N_f$:
Frequency-reuse factor

Small Cells, LiFi, FFR, HetNets & all that...
LS-MIMO Applications: Multilayer Sectorization

- Zheng, Zhao, Mei, Shao, Xiang & Hanzo: Survey of Large-Scale MIMO Systems, IEEE Communications Surveys & Tutorials, IEEE Xplore

Shannon’s Lesson # 3 - The SINR Depends on the Pathloss & Fading of Both the Signal & Interference

Type I MIMO: Space-Time Coded OFDM Improves the SINR
Spatial Corr. Degrades the $G_2$ STBC SINR

![Graph showing BER vs. SNR for different correlation coefficients](image)

So, Dr Shannon - which of the Four MIMOs is fit for Large-Scale MIMOs?

- Diversity - STBC, etc.
- Multiplexing - BLAST, etc.
- Beamforming
- Space Division Multiple Access

CSI Errors Degrade the SINR of $G_2$ STBC

![Graph showing BER vs. SNR for different CSI errors](image)

Shannon’s Lesson # 4 - $M$: No. of TX antennas

**Capacity of MIMOs**

$$C \approx \min(M; N)$$

Large-scale MIMOs and Spatial Modulation

Given your legacy Dr Shannon - we set out to conceive cooperative massive MIMO-aided unlicensed & optical wireless HetNets...

LS-MIMO Applications:
Adaptive Beamforming

• Zheng, Zhao, Mei, Shao, Xiang & Hanzo: Survey of Large-Scale MIMO Systems, IEEE Communications Surveys & Tutorials, IEEE Xplore

LS-MIMO Applications:
Large-scale Cooperation & Backhaul

• Zheng, Zhao, Mei, Shao, Xiang & Hanzo: Survey of Large-Scale MIMO Systems, IEEE Communications Surveys & Tutorials, IEEE Xplore
LS-MIMO Applications: Hot-Spot Coverage

- Zheng, Zhao, Mei, Shao, Xiang & Hanzo: Survey of Large-Scale MIMO Systems, IEEE Communications Surveys & Tutorials, IEEE Xplore

The Fifth MIMO: Spatial Modulation (SM) Requires Only a Single RF Chain


But Dr Shannon... Do You Believe Losing Transmit-Diversity in Exchange for Requiring Only a Single-RF Chain Is a Good Deal?


So What About Single vs. Multiple RF Chains...Dr Shannon...?


Linear Dispersion Coding (LDC) Circumvents the Diversity vs. Multiplexing Tradeoff

- Capacity comparison between V-BLAST, STBC, LDC, SM and STSK:
  - Both V-BLAST(2,2) and LDC(2,2,2,4) may achieve the same maximum attainable capacity of the MIMO system using $M = 2$ TAs and $N = 2$ RAs.
  - The SM(2,2)'s CCMC capacity is lower than that of V-BLAST(2,2) and LDC(2,2,2,4), followed by G2-STBC(N=2) and STSK(2,2,2,4).

- BER performance comparison between V-BLAST, STBC and LDC:
  - Both the diversity schemes of LDC(2,2,2,4) and G2-STBC(N=2) may outperform the multiplexing scheme of V-BLAST(2,2).
  - The MMSE receiver imposes substantial performance loss both to V-BLAST(2,2) and LDC(2,2,2,4).

• Linear Dispersion Codes Require Multiple RF Chains
  - LDC($MNTQ$), with arbitrary modulation schemes.
  - $Q$ non-separable layers.
  - Optimization of $\chi$.
  - A single Dispersion Character Matrix (DCM) $\chi$.

• Diversity vs. Multiplexing Tradeoff
  - The same trends may be observed, when LDC is compared to STSK, because the LDC receiver may employ the V-BLAST detectors, while the STSK receiver may employ the SM detectors.

- The SM(2,2) detector exhibits a comparably low detection complexity to that of the linear MMSE aided V-BLAST(2,2) detector, which are both substantially lower than that of the ML V-BLAST(2,2) detector.
  - The performance difference between SM(2,2) and V-BLAST(2,2) is almost negligible compared to the performance loss imposed by employing MMSE detector for V-BLAST.

- The same trends may be observed, when LDC is compared to STSK, because the LDC receiver may employ the V-BLAST detectors, while the STSK receiver may employ the SM detectors.
In This Scenario Single-RF Spatial Modulation Is Capable of Matching the ML-Detected BLAST Performance at a Fraction of Its Complexity, BUT...

- SM is not faultless, because it fails to achieve the full MIMO capacity;
- This leaves room for its development into generalized SM, where several symbols per channel use would be transmitted;
- Regrettfully, then the inter-antenna interference would resurface...;

So, what are we to do Dr Shannon...?
A Stroll with Shannon Along ’Quantum Avenue’...?

- [Hanzo et al.] Wireless Myths, Realities and Futures, Proc. of the IEEE, 13th of May 2012, Centennial Issue, Xplore Open Access

- [Botsinis, Ng & Hanzo]: Quantum Search Algorithms, Quantum Wireless and a Low-Complexity Maximum Likelihood Iterative Quantum Multi-User Detector Design, IEEE Access, May 2013, Xplore Open Access