

A Stroll with Shannon to Next-Generation

Plaza:

Large-Scale MIMOs, Single versus Multiple RF Chains and All That...

Presented by
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with

SOUTHAMPTON WIRELESS

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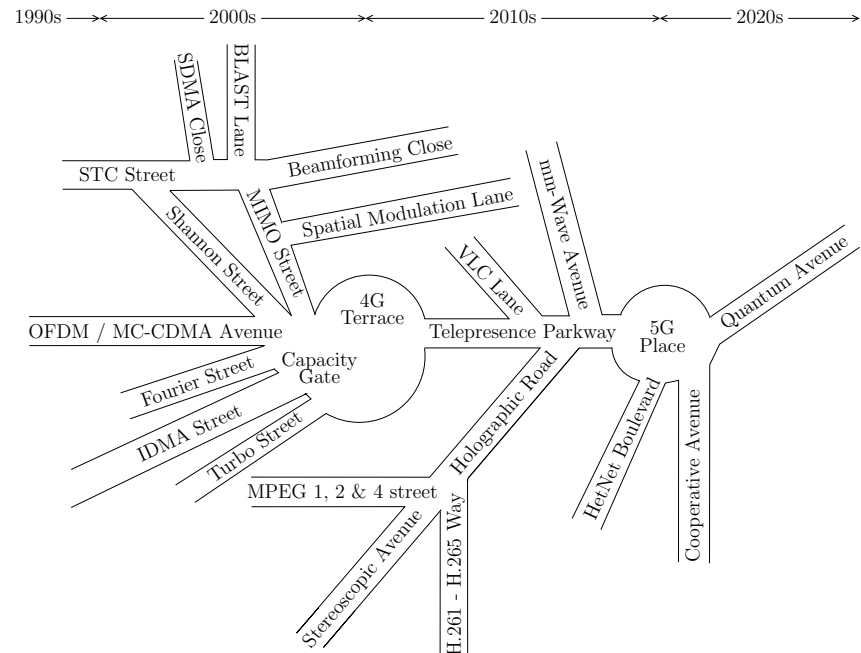
A Stroll with Shannon to Next-Generation

Plaza...

• The History...

Acknowledgements

- Sincere thanks for the cordial invitation to all the Organizers
- The Southampton Wireless team, especially to my valued friends and colleagues Shinya Sugiura, Mohammad Kadir, Ping Yang, Kan Zheng, Chao Xu;
- The SM pioneers Ali Ghayeb, Harald Haas, Prof. Jeganathan, Marco di Renzo, Rakshith Rajashekar, Prof. Hari *et al.*
- The Sponsors: EPSRC and the ERC Advanced Fellow Grant



A Stroll with Shannon to Next-Generation

Plaza...

- **The Myth:** 'flawless tele-presence' with zero error for anyone, anywhere, anytime...
- **The Reality...**
- **The Future:** L. Hanzo, H. Haas, S. Imre, D. O'Brien, M. Rupp, and L. Gyongyosi, "Wireless myths, realities, and futures: From 3G/4G to optical and quantum wireless," Proceedings of the IEEE, vol. 100, pp. 1853–1888, 13 2012, Invited Paper in the Centennial Issue

A Stroll with Shannon...

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

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**
5. L. Hanzo, M. El-Hajjar, O. Alamri: *Near-Capacity Wireless Transceivers and Cooperative Communications in the MIMO Era: Evolution of Standards, Waveform Design, and Future Perspectives Proceedings of the IEEE Volume 99, Issue 8, 2011, pp 1343 - 1385*

Shannon's Lesson # 1 - B : Bandwidth mm-Wave & Optical Wireless

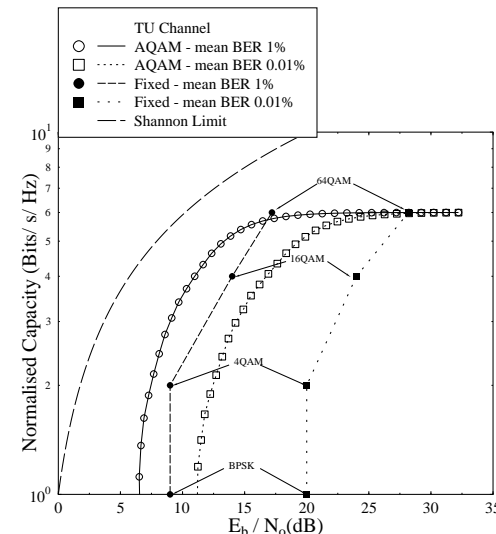


Figure 1: Channel capacity upper bound of LTE-style near-instantaneously adaptive QAM (AQAM) and fixed modulation schemes over the dispersive TU Rayleigh Fading channel for BER=1% and BER=0.01%.

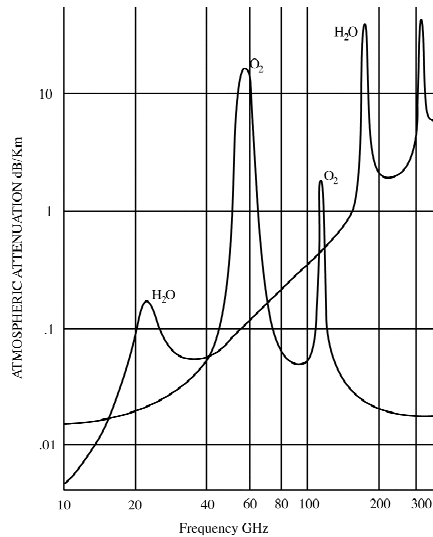


Figure 2: Pathloss versus carrier frequency, portraying the typical oxygen and water vapour absorption phenomena ©Steele & Hanzo, 1999

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

- http://www.vlcc.net/?ml_lang=en
- <http://www.lificonsortium.org/index.html>
- **The Future:** L. Hanzo, H. Haas, S. Imre, D. O'Brien, M. Rupp, and L. Gyongyosi, "Wireless myths, realities, and futures: From 3G/4G to optical and quantum wireless," Proceedings of the IEEE, vol. 100, pp. 1853–1888, 13 2012, Invited Paper in the Centennial Issue



**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...?**

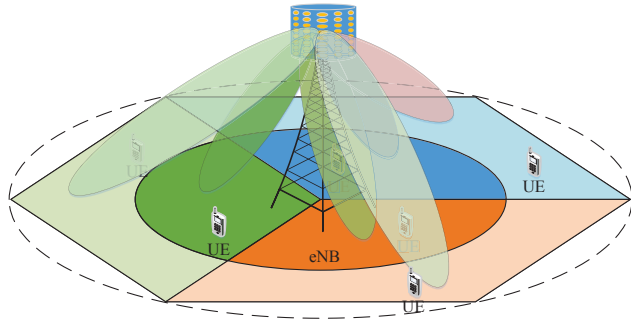
What about 'Green Radio...?

What about the 'Tactile Internet'...?

**Shannon's Lesson # 2 - N_f :
Frequency-reuse factor**

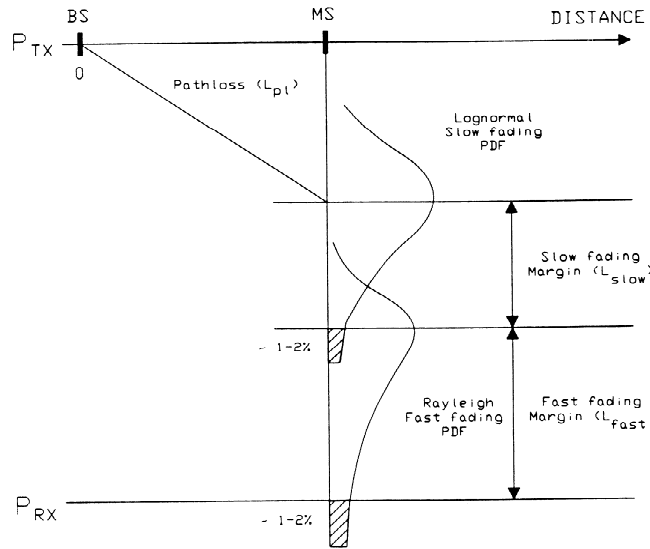
Small Cells, LiFi, FFR, HetNets & all that...

LS-MIMO Applications: Multilayer Sectorization

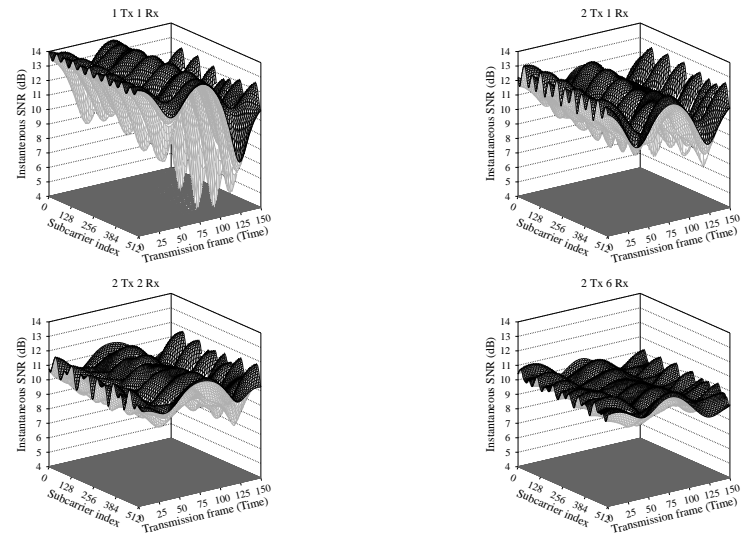


- Zheng, Zhao, Mei, Shao, Xiang & Hanzo: Survey of Large-Scale MIMO Systems, IEEE Communications Surveys & Tutorials, IEEE Xplore

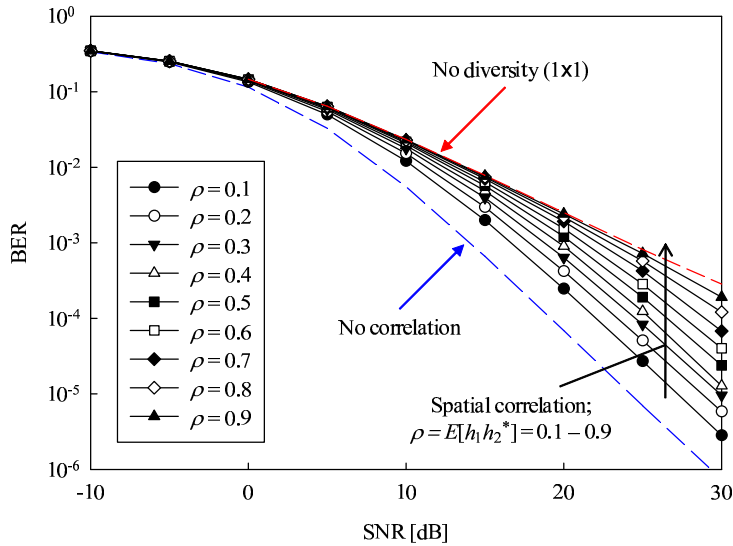
Shannon's Lesson # 3 - The SINR Depends on the Pathloss & Fading of Both the Signal & Interference



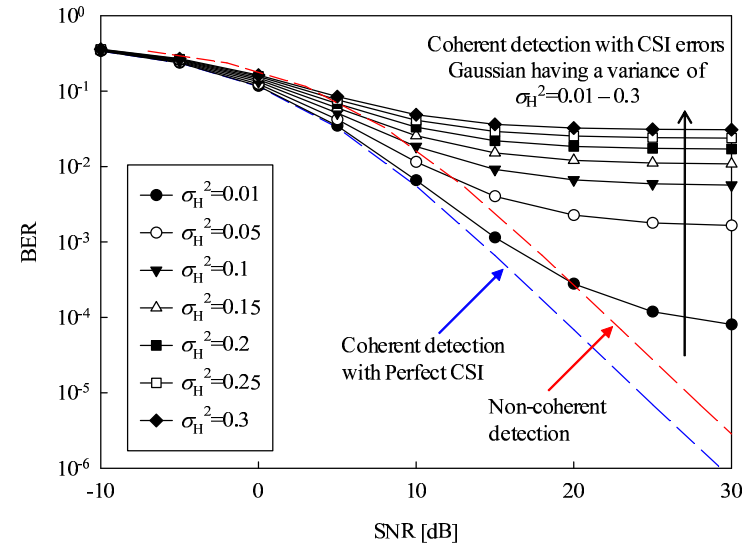
Type I MIMO: Space-Time Coded OFDM Improves the SINR



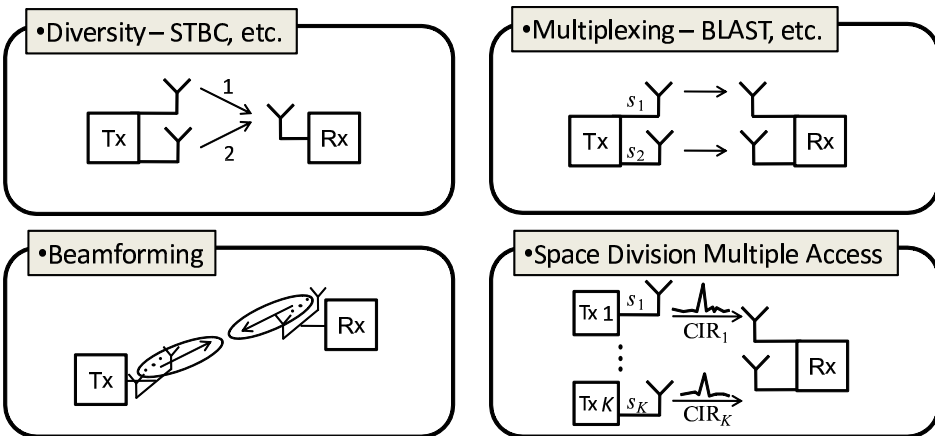
Spatial Corr. Degrades the G_2 STBC SINR



CSI Errors Degrade the SINR of G_2 STBC



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



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

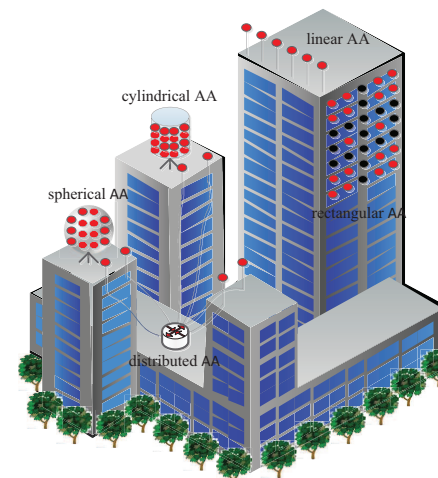
Capacity of MIMOs

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

Large-scale MIMOs and Spatial Modulation

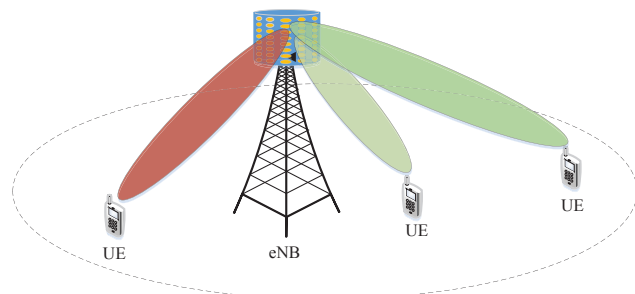
- L. Hanzo, O. Alamri, M. El-Hajjar, N. Wu: Near-Capacity Multi-Functional MIMO Systems; John Wiley and IEEE PRESS, 2009

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



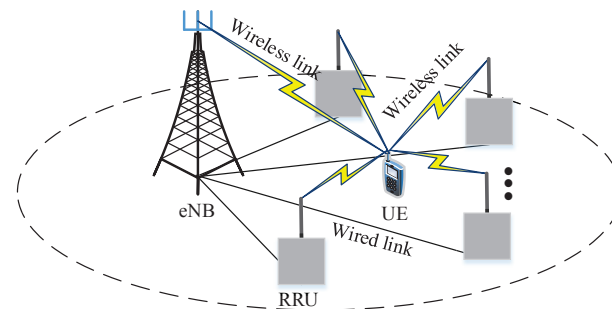
Given your legacy Dr Shannon - we set out to conceive cooperative massive MIMO-aided unlicensed & optical wireless HetNets...

LS-MIMO Applications: Adaptive Beamforming



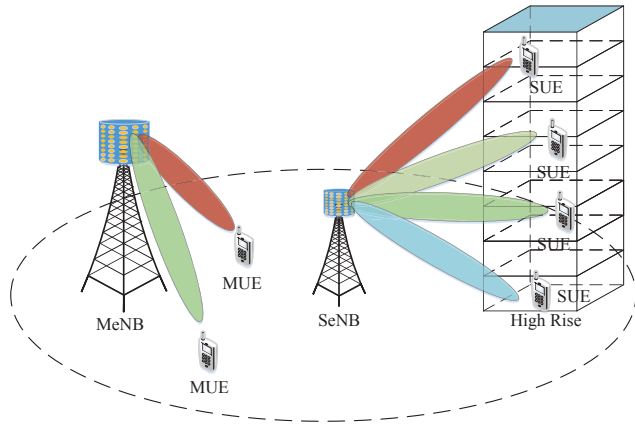
- Zheng, Zhao, Mei, Shao, Xiang & Hanzo: Survey of Large-Scale MIMO Systems, IEEE Communications Surveys & Tutorials, IEEE Xplore

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

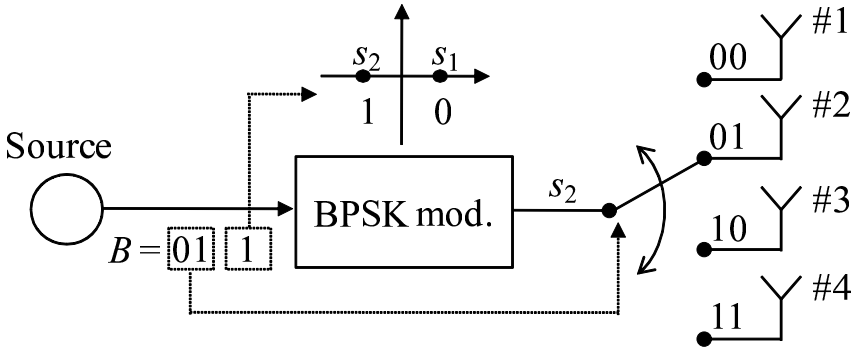
LS-MIMO Applications: Hot-Spot Coverage



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

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

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

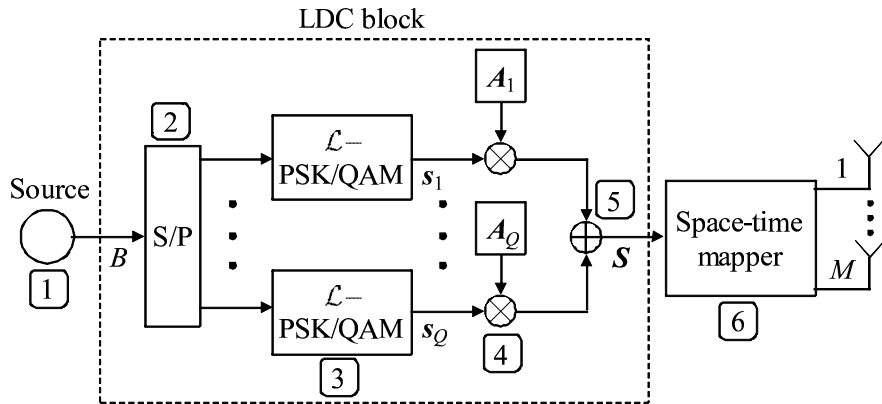


- M. Di Renzo, H. Haas, A. Ghrayeb, S. Sugiura and L. Hanzo: Spatial Modulation for Generalized MIMO: Challenges, Opportunities and Implementation, Proc. of the IEEE, January 2014

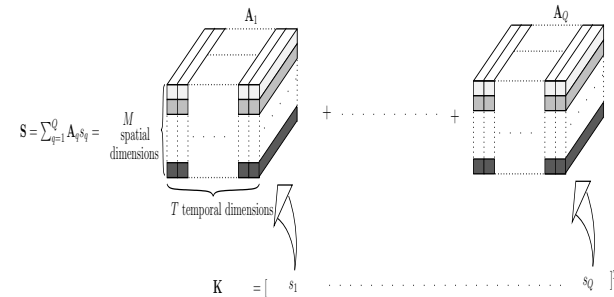
So What About Single vs. Multiple RF Chains...Dr Shannon...?

1. S. Sugiura, S. Chen, and L. Hanzo, "A universal space-time architecture for multiple-antenna aided systems," *Communications Surveys Tutorials, IEEE*, vol. 14, pp. 401 –420, quarter 2012.
2. M. Di Renzo, H. Haas, A. Ghrayeb, S. Sugiura and L. Hanzo: Spatial Modulation for Generalized MIMO: Challenges, Opportunities and Implementation, Proc. of the IEEE, January 2014

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

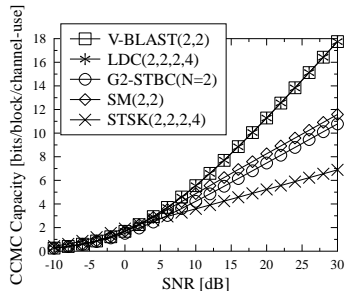


Linear Dispersion Codes Require Multiple RF Chains



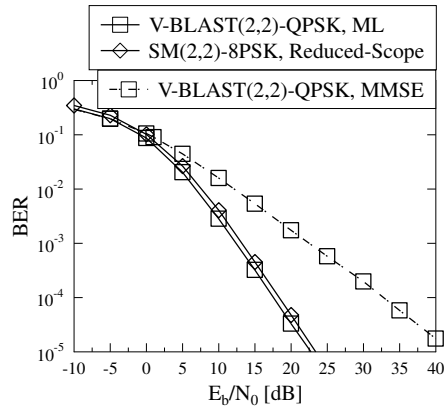
- LDC($MNTQ$), with arbitrary modulation schemes.
- Q non-separable layers.
- Optimization of χ .
- A single Dispersion Character Matrix (DCM) χ .

- Capacity comparison between V-BLAST, STBC, LDC, SM and STSK:



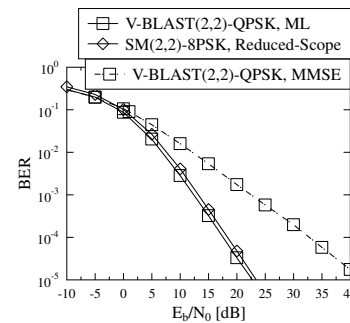
- Both V-BLAST(2,2) and LDC(2,2,2,4) may achieve the same maximum attainable capacity of the MIMO system using $M = 2$ TAs and $N = 2$ RAs.
- The SM(2,2)'s CCMC capacity is lower than that of V-BLAST(2,2) and LDC(2,2,2,4), followed by G2-STBC(N=2) and STSK(2,2,2,4).

- 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 to LDC(2,2,2,4).

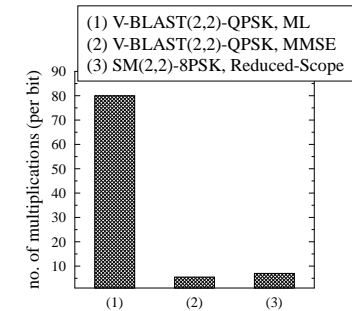
- BER performance of V-BLAST and SM:



- 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.

- Complexity of V-BLAST and SM:



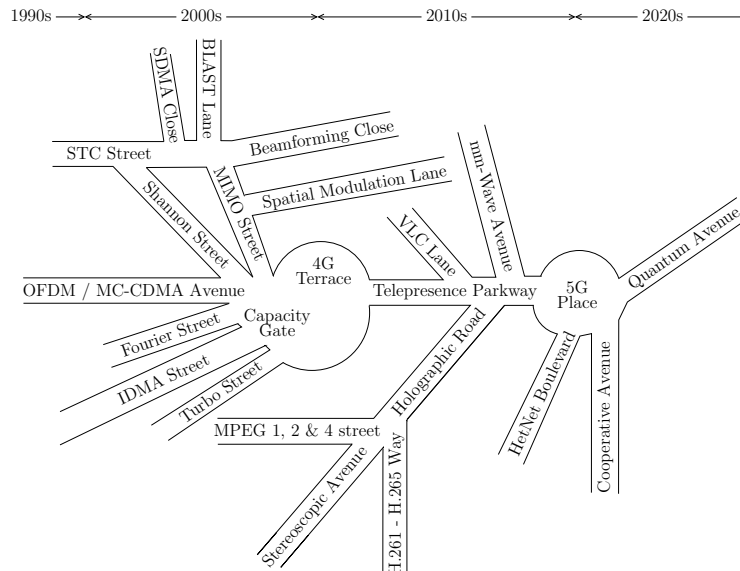
- The SM(2,2) detector exhibits a comparably low detection complexity to that of the linear MMSE aided V-BLAST(2,2) detector, which are both substantially lower than that of the ML V-BLAST(2,2) detector.

In This Scenario Single-RF Spatial Modulation Is Capable of Matching the ML-Detected BLAST Performance at a Fraction of Its Complexity, BUT...

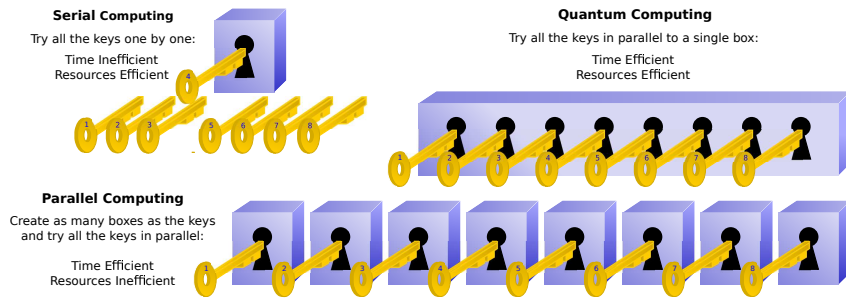
- SM is not faultless, because it fails to achieve the full MIMO capacity;
- This leaves room for its development into generalized SM, where several symbols per channel use would be transmitted;
- Regretfully, then the inter-antenna interference would resurface...;
- Sugiura, S.; Hanzo, L.: Single-RF Spatial Modulation Requires Single-Carrier Transmission: Frequency-Domain Turbo Equalization for Dispersive Channels, IEEE Transactions on Vehicular Technology, 2015, DOI: 10.1109/TVT.2014.2370679 IEEE Early Access

So, what are we to do Dr Shannon...?

A Stroll with Shannon Along 'Quantum Avenue'?



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