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Quantum-Inspired Downlink MU-MIMO Vector Perturbation Precoding

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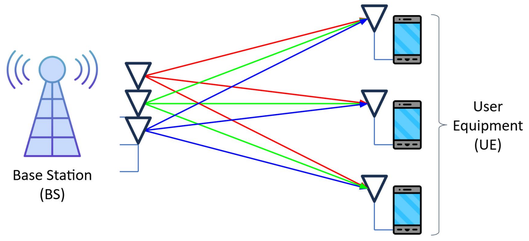
Overview

Downlink Multi-User Multiple-Input Multiple-Output (MU-MIMO) precoding enables massive network capacity benefits with minimal interference. However, conventional linear precoding fails when a user's channel is poorly conditioned or when multiple users' channels are highly correlated with each other. **Vector Perturbation Precoding (VPP)** is a non-linear technique that targets those scenarios, but the classically optimal method is too computationally heavy.

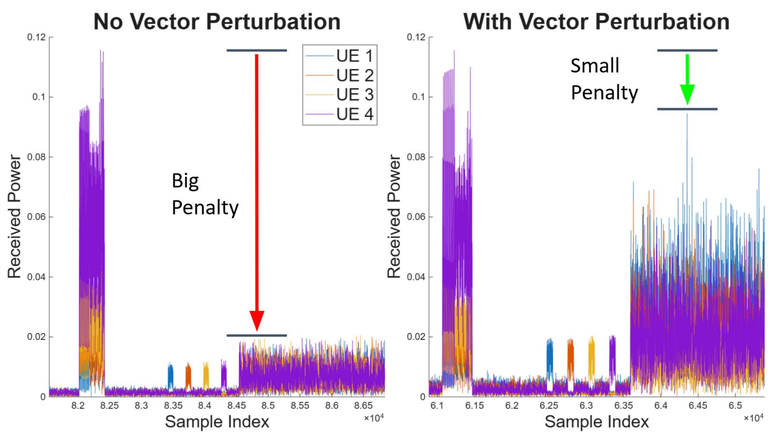
This project aims to leverage quantum-inspired computing to accelerate VPP, evaluating our quantum-inspired solver with real-time over-the-air (OTA) experiments on software-defined radio (SDR).

Background



MU-MIMO allows a BS to handle many individual concurrent streams, and downlink is when the BS is transmitting to the individual UEs. This creates interference that precoding is designed to mitigate.

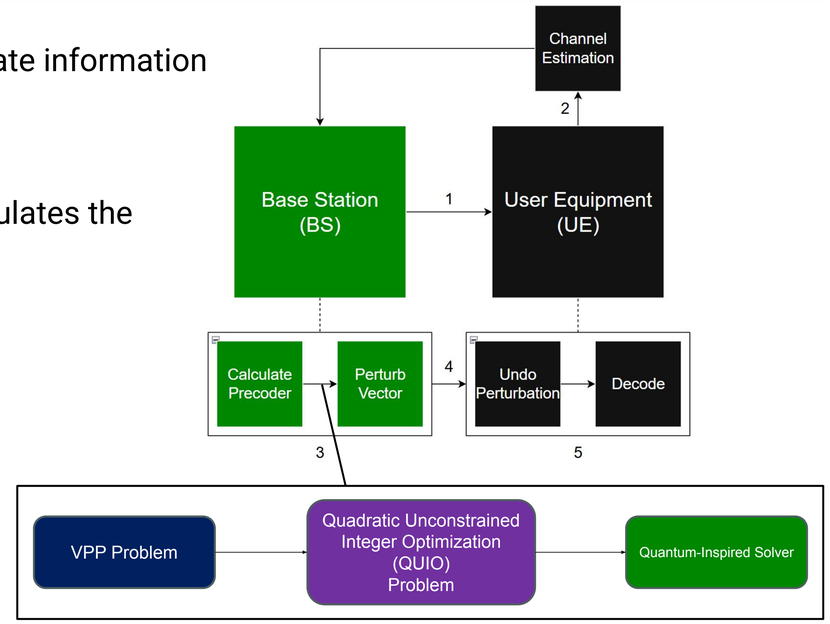
However, if one of the UEs has a weaker link, the linear precoder sacrifices the transmission power towards the other UEs to accommodate for the weakest link.



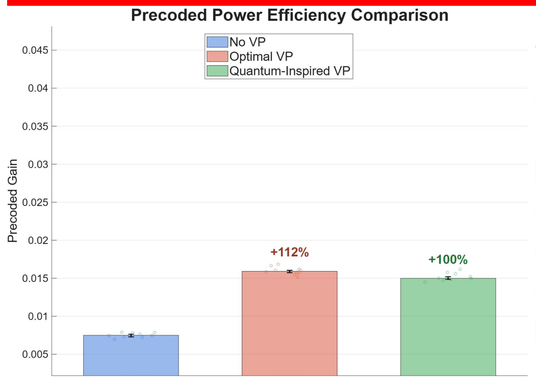
VPP is shown to provide a massive increase in signal power per user at the receiver compared to the wasted power due to conventional linear precoding.

System Design and Architecture

1. BS sends known pilot signal to UEs
2. UEs estimate the channel and feed back the channel state information (CSI) to BS through shared storage
3. BS calculates precoder and perturbs the vector
4. BS sends precoded signal downlink to UEs
5. UE receives the signal, undoes the perturbation, demodulates the symbols to bits, and then decodes.

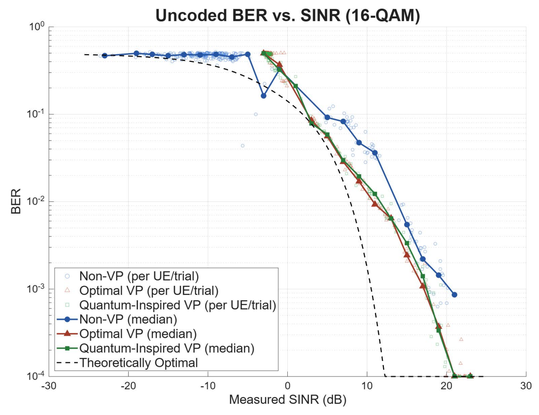


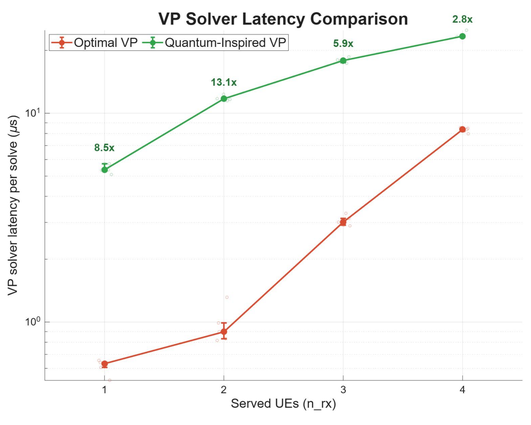
Results



The power efficiency of VPP for 16-QAM 4x4 MIMO is more than double the power efficiency of conventional linear precoding.

Vector Perturbation (VP) provides a lower bit-error-rate (BER) than traditional precoding, and our quantum-inspired approach maintains optimal accuracy.





Our quantum-inspired approach scales better with MIMO size than the classically optimal method. Up to 4x4 MIMO, the quantum-inspired approach is slower but is expected to outperform at 6x6 and higher.

Conclusions

Vector Perturbation Precoding (VPP) was empirically proven through real-time over-the-air experiments to be superior in both power efficiency and BER compared to conventional linear precoding.

Our quantum-inspired solver maintains near-equivalent accuracy to the classically optimal solver while scaling efficiently with increasing MIMO sizes.

Future Work

- Evaluate Vector Perturbation latency at higher MIMO sizes (6x6 and 8x8)
- Experiment with higher modulation orders (64-QAM)
- Optimize solver parameters to drive down latency while maintaining optimal accuracy

Acknowledgements

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References

1. S. Kasi, A. K. Singh, D. Venturelli and K. Jamieson, "Quantum Annealing for Large MIMO Downlink Vector Perturbation Precoding," ICC 2021 - IEEE International Conference on Communications, Montreal, QC, Canada, 2021, pp. 1-6, doi: 10.1109/ICC42927.2021.9500557.

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