Interactive Interference Alignment

Quan Geng and Pramod Viswanath
Department of ECE, University of Illinois Urbana Champaign

3-7 September 2012 IEEE Information Theory Workshop (ITW) 2012 Lausanne, Switzerland

Abstract

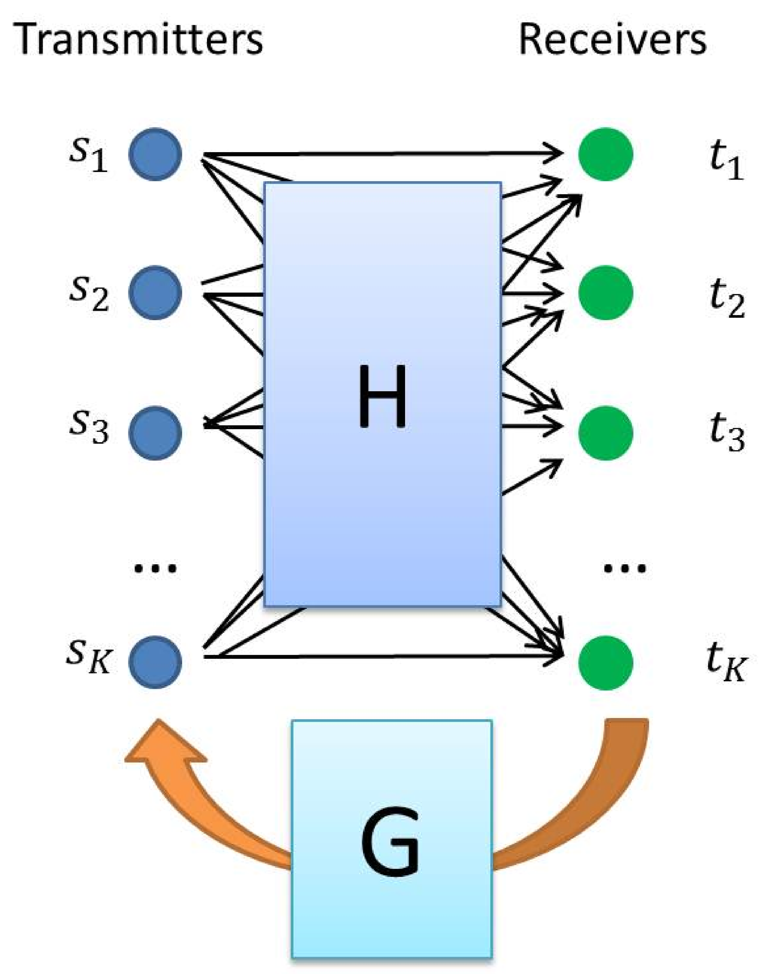
We study interference channels (IFC) where the sources can also listen and destinations can also transmit, either via simultaneous out of band transmission or via in band half duplex transmission. The flexibility afforded by feedback and interaction allows for the derivation of interference alignment (IA) strategies that have desirable "engineering properties": insensitivity to the rationality or irrationality of channel parameters, small block lengths, finite SNR operations. Degree of freedom calculations are supplemented by numerical evaluations of finite SNR performance.
We also discuss how full duplex antennas can help achieve interference alignment.

Motivation

- IFC has been well studied in information theory, but existing schemes (IA) have drawbacks which make it challenging to implement in practical communication systems
  - require very long blocklength and a large number of channel diversities
  - sensitive to whether channel coefficients are rational or irrational
- The drawbacks may be due to the nature of the channel model which assumes TXs can only transmit and RXs can only listen, while in practice radios can both transmit and receive.
- We study a new channel model where RXs can also talk back to TXs using a reciprocal feedback channel.
- The feedback channel enables flexibility in designing simple interference alignment scheme and achieve the optimal degrees of freedom.
- Furthermore, we study how full duplex antennas can help do interference alignment.

System Model

Figure: System Model



We assume there is a feedback communication channel from receivers to transmitters. This can be achieved via out of band transmission or in band half duplex.

Transmission Scheme

Figure: Phase 1

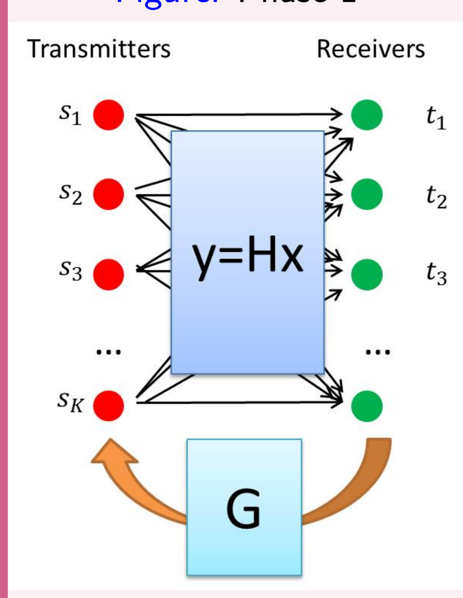


Figure: Phase 2

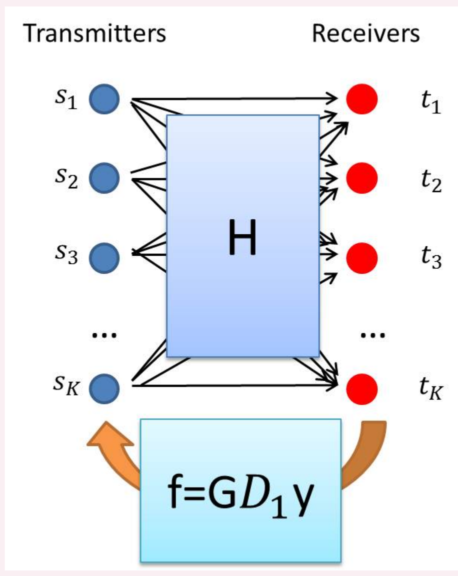
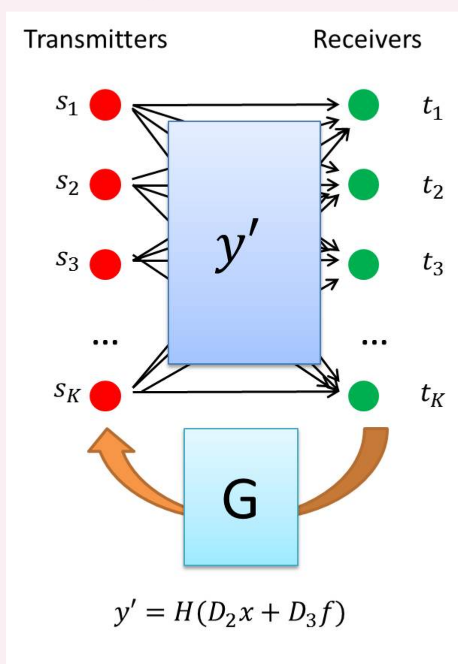


Figure: Phase 3



- Phase1: TXs send independent symbols simulatenously, and RXs get $y = Hx$.
- Phase2: After receiving signals from TXs in phase1, all RXs scale y and send back to TXs using the feedback channel. TXs get $f = GD_1y$.
- Phase3: Each TX has two sets of signals x and f, and TXs send out a linear combination of x and f to RXs. RXs get $y' = H(D_2x + D_3f) = (HD_2 + HD_3GD_1H)x$.

Interference Aligment (IA) Conditions

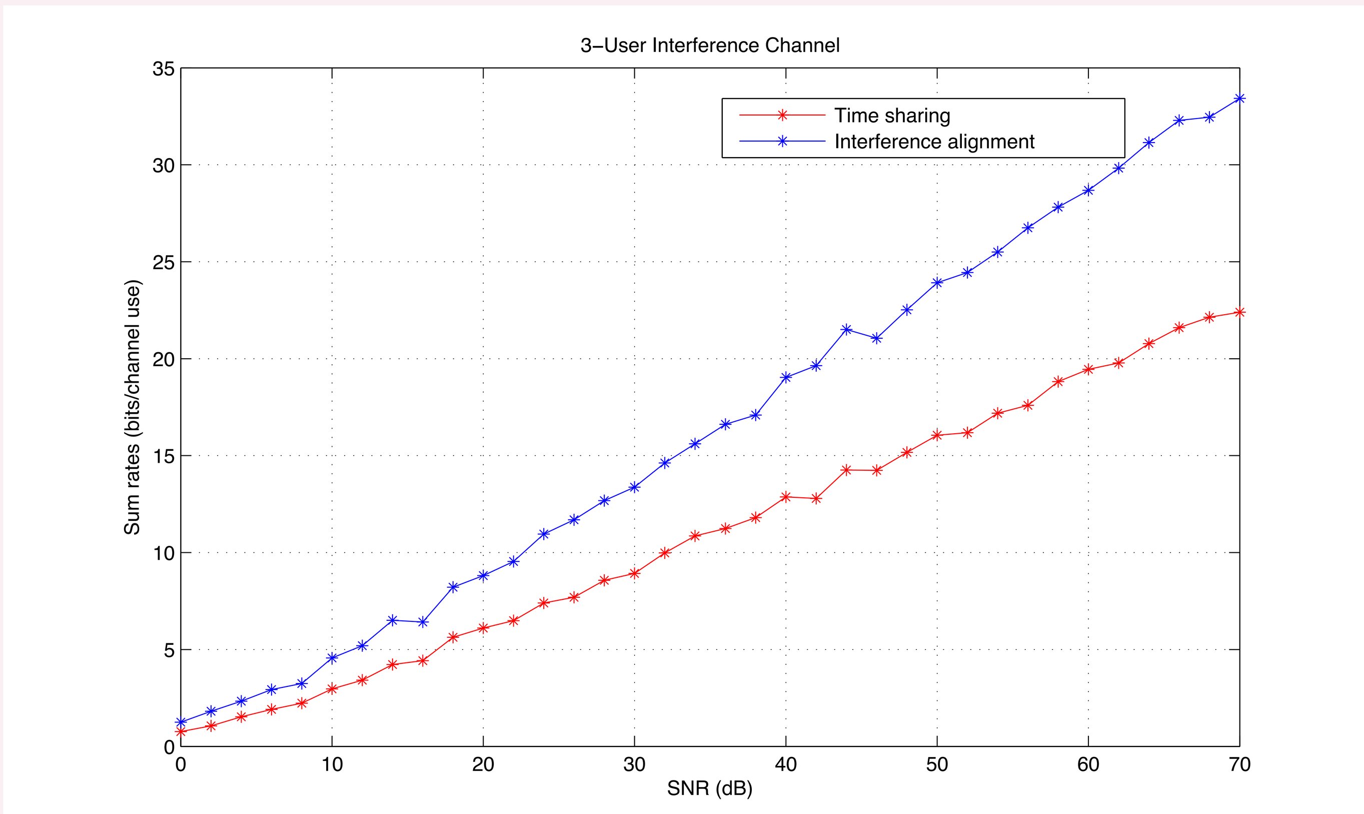
If diagonal coding matrices D_1, D_2, D_3 satisfy that each row of $(HD_2 + HD_3GD_1H)$ is proportional to the corresponding row of H except the diagonal entries, then interferences are aligned at each receiver, and RXs can do interference cancellation with y and y', achieving the optimal degrees of freedom $\frac{K}{2}$.
Question: Do the desired coding matrices D_1, D_2, D_3 exist?

Main Results on Interactive IA

- The existence of diagonal coding matrices can be reduced to the problem of checking existence of solutions to a system of polynomial equations (well studied in algebraic geometry for algebraically closed field, e.g., $\mathbb{C}$).
- Solutions exist $\Leftrightarrow$ Gröbner Basis of polynomials does not contain the trivial polynomial $\{1\}$.
- Closed-form solution for $K = 3$.
- Affirmative numeric verfications for $K = 4$. (Symbolic computations of Gröbner Basis are computationally hard)
- Further numeric simulations suggest two feedback transmissions are needed and sufficient for $K = 5$ and $K = 6$.

Average Finite SNR Performance over i.i.d. Rayleigh Fading Channels

Figure: 3-User Interference Channel

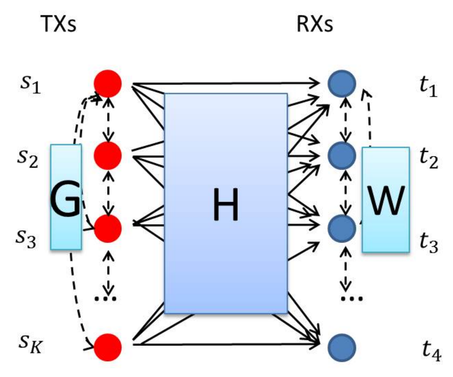


IA with Full-Duplex(FD) Antennas

Full duplex antenna can transmit and receive at the same time in the same band. With full duplex anntennas, interference alignment are easier to achieve (feedback channel is not necessary).

System Model with FD Antennas

Figure: With FD antennas, all nodes can transmit and receive in the same band simultaneously.



Two-Phase Transmission Scheme

- Phase 1: All TXs send out signals x simulatenously. After the transmission, TXs get Gx and RXs get Hx.
- Phase 2: TXs send out a linear combination of x and Gx, and RXs send out scaled version of Hx. Therefore, RXs get $H(D_1x + D_2Gx) + WD_3Hx = (HD_1 + HD_2G + WD_3H)x$.

Main Results on IA with FD Antennas

The same IA conditions as in the case with feedback channel.

- Closed-form solution for $K = 3$ and $K = 4$, and thus achieves the optimal $\frac{K}{2}$ degrees of freedom.
- We can prove that for 4-User MIMO IFC with M full-duplex antennas, the scheme can achieve the optimal $\frac{KM}{2} = 2M$ degrees of freedom.

Conclusion

- Simple interactive interference alignment scheme for interference channel with feedback channel or full duplex antennas
  - channel diversity is not required
  - insensitive to whether H is rational or irrational
  - linear operations at all nodes
  - interference creates relay opportunity, and the scheme works even if direct links are missing
  - design of coding coefficients only involves with solving polynomial or linear equations
- Prove the feasibility and optimality of the scheme for small K
- Numeric Finite SNR Performance Analysis