A Game Theoretic DRA Approach for Improved Spread Spectrum Frequency Hopped Waveforms Performance in the Presence of Smart Jammers

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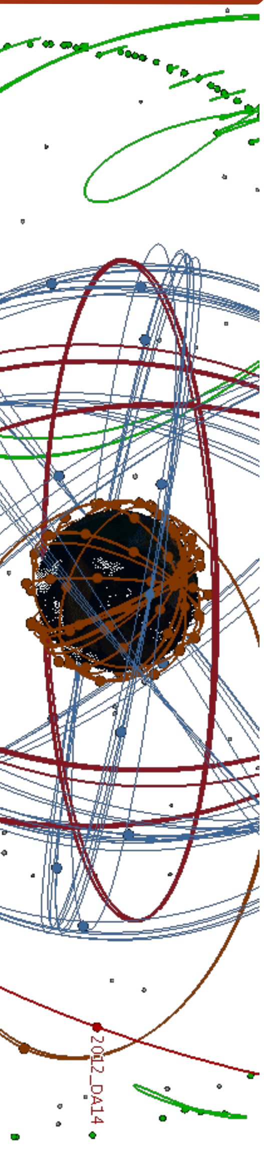
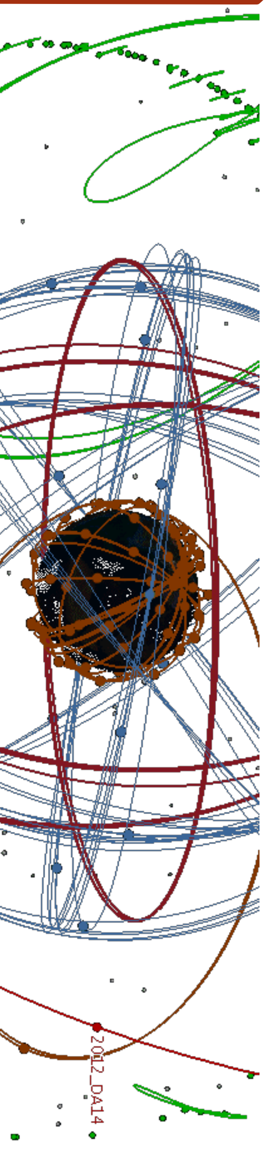
Outline



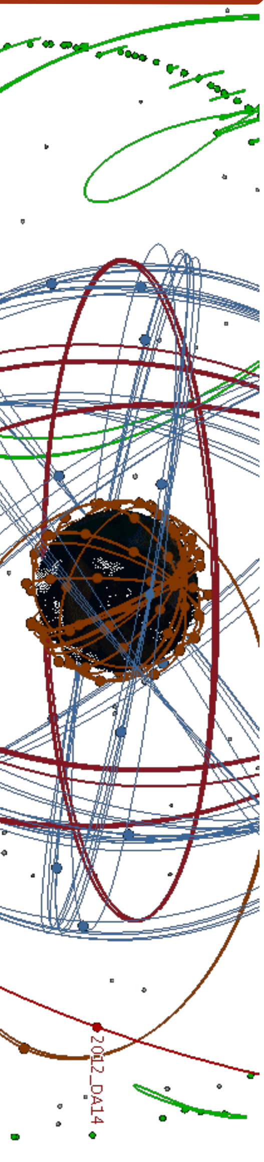
- Introduction
- Literature Review (Game theory and its applications in Wireless Communication)
- Proposed Dynamic Game DRA for SATCOM
- Numerical Simulations
- Conclusions

Introduction

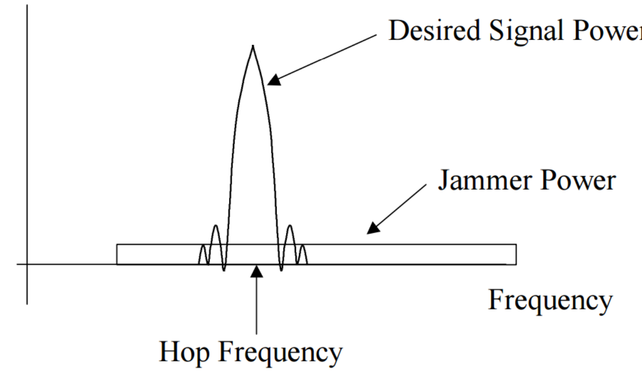


- Jamming: Intentional RF interference to harm wireless communications.
- As technology advances, adversaries have increasingly sophisticated capabilities to jam transmissions over satellites.
- There are several types of jamming for wireless communication
  - Proactive jammer
  - Reactive jammer
  - Smart jammer
- In general Anti-jamming can be done in multiple domains: space, time, frequency, modulation, and coding

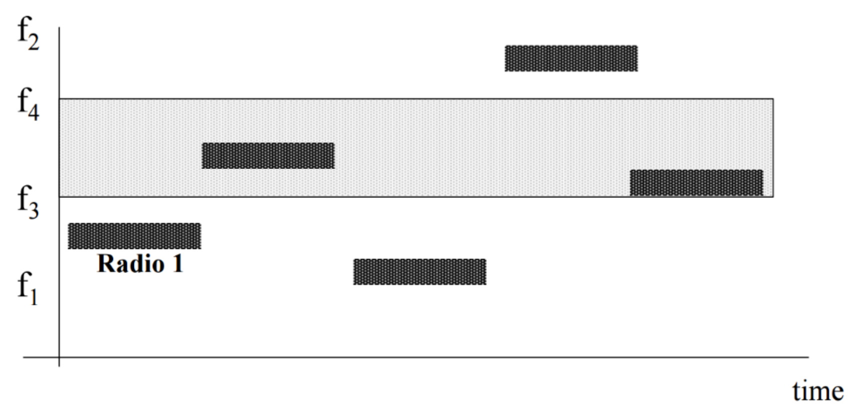
FHSS for Hostile Jamming (1)

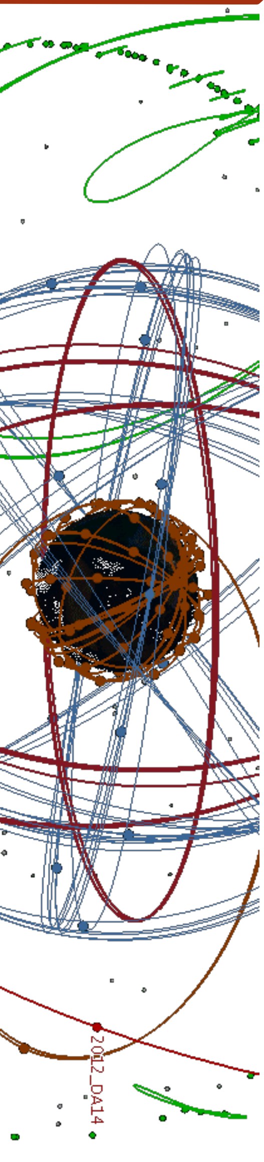


- FHSS for Full band Jamming
  - Generally, FHSS signals have much stronger power



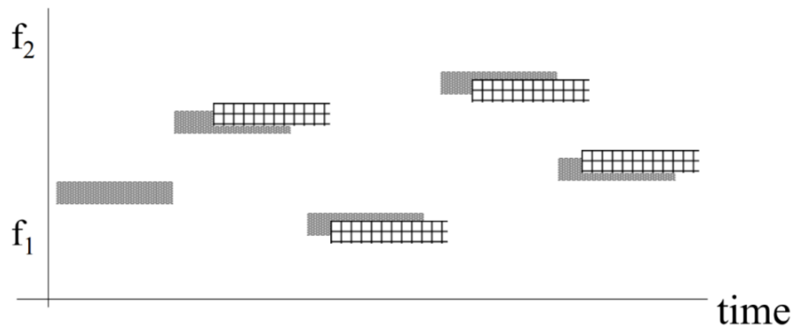
- FHSS for Partial Band Jamming
  - The partial band jammer can cause more problems for uncoded transmission of FHSS



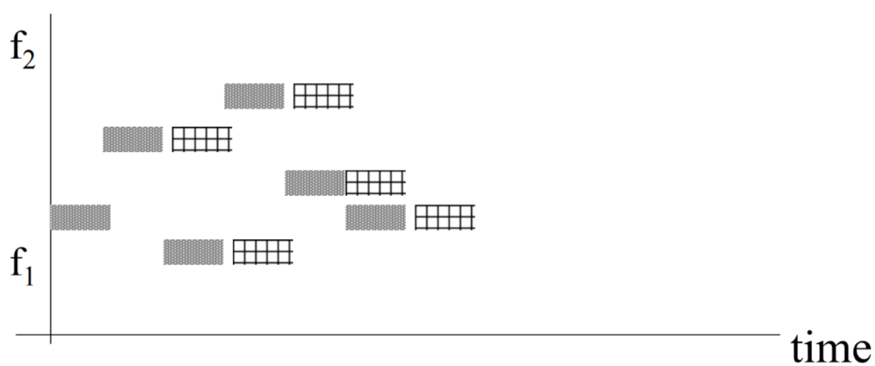


FHSS for Hostile Jamming (2)

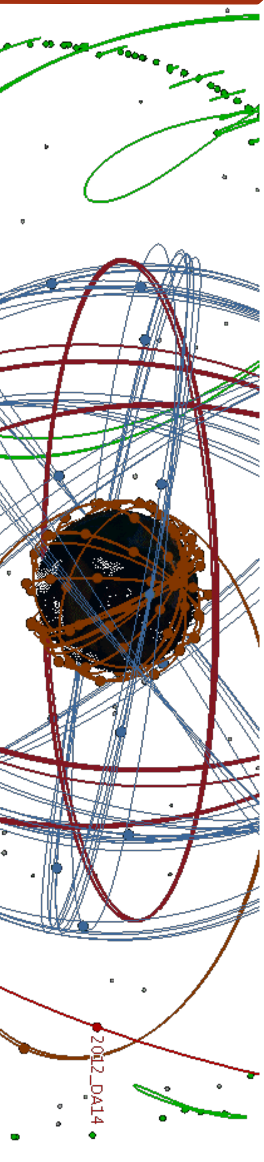
- FHSS for Follow-along Jamming
  - Jammer monitors the transmitted signals and concentrates all power in that band



  - FHSS can either hops faster than the jammer can adapt to mitigate the follow-along jamming

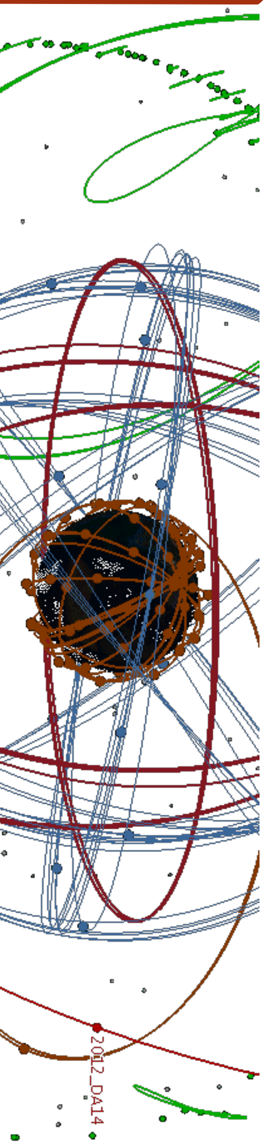


Game Theory



- … is a mathematical framework to model and analyze conflicts among a group of entities
  - Each entity is called a player.
  - The system states depend on the joint control of all players.
  - The interest of a player is usually modelled by a cost/utility/payoff function.
  - The equilibrium strategies are chosen by players to maximize their individual payoffs.
  - Nash equilibrium is a state, in which no player can improve his payoff by changing his strategy.

Applications in Wireless Comm.

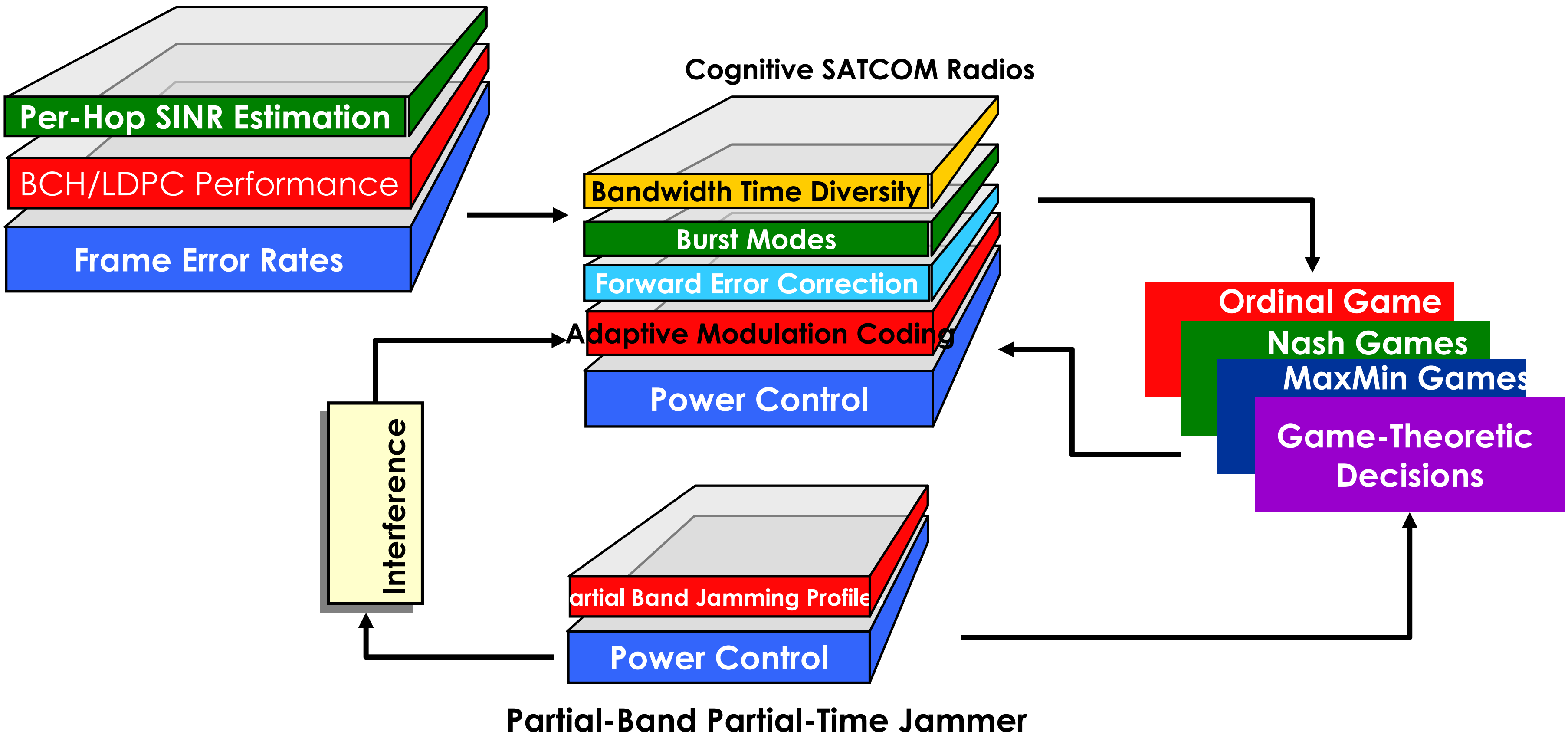


OSI Layer	Application field	Specific application
Physical	Power control	Power control for CDMA Power management in MIMO
Data link	Medium access control	Access to slotted Aloha, random access to the interference channel
Network	Routing	Routing and forwarding
Transport	Cell selection	Inter-cell and intra-cell games

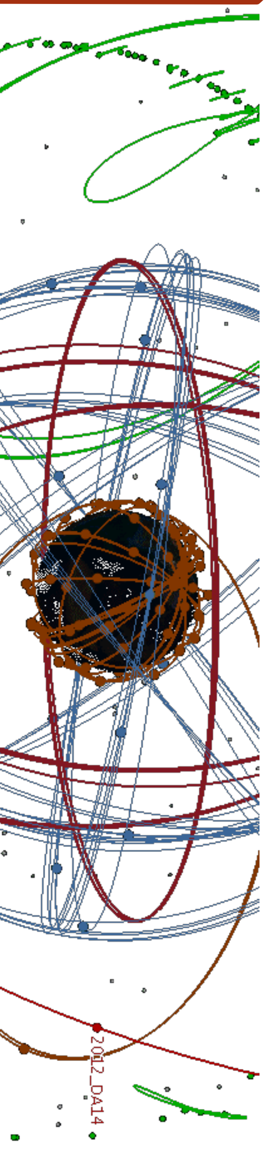
Specific application	Objective	Game type
Power control for CDMA	Set transmission power in order to maximize SNIR with minimum interference	Non-cooperative
Power management in MIMO	Power allocation in links to minimize interference	Non-cooperative
Random access to the interference channel	Share access to an interference channel	Non-cooperative
Routing and Forwarding	Decide if a packet from another node should be forwarded or not. Choose the optimal path	Non-cooperative
Inter-cell and intra-cell games	Decide which cell can best fulfill service requirements	Non-cooperative

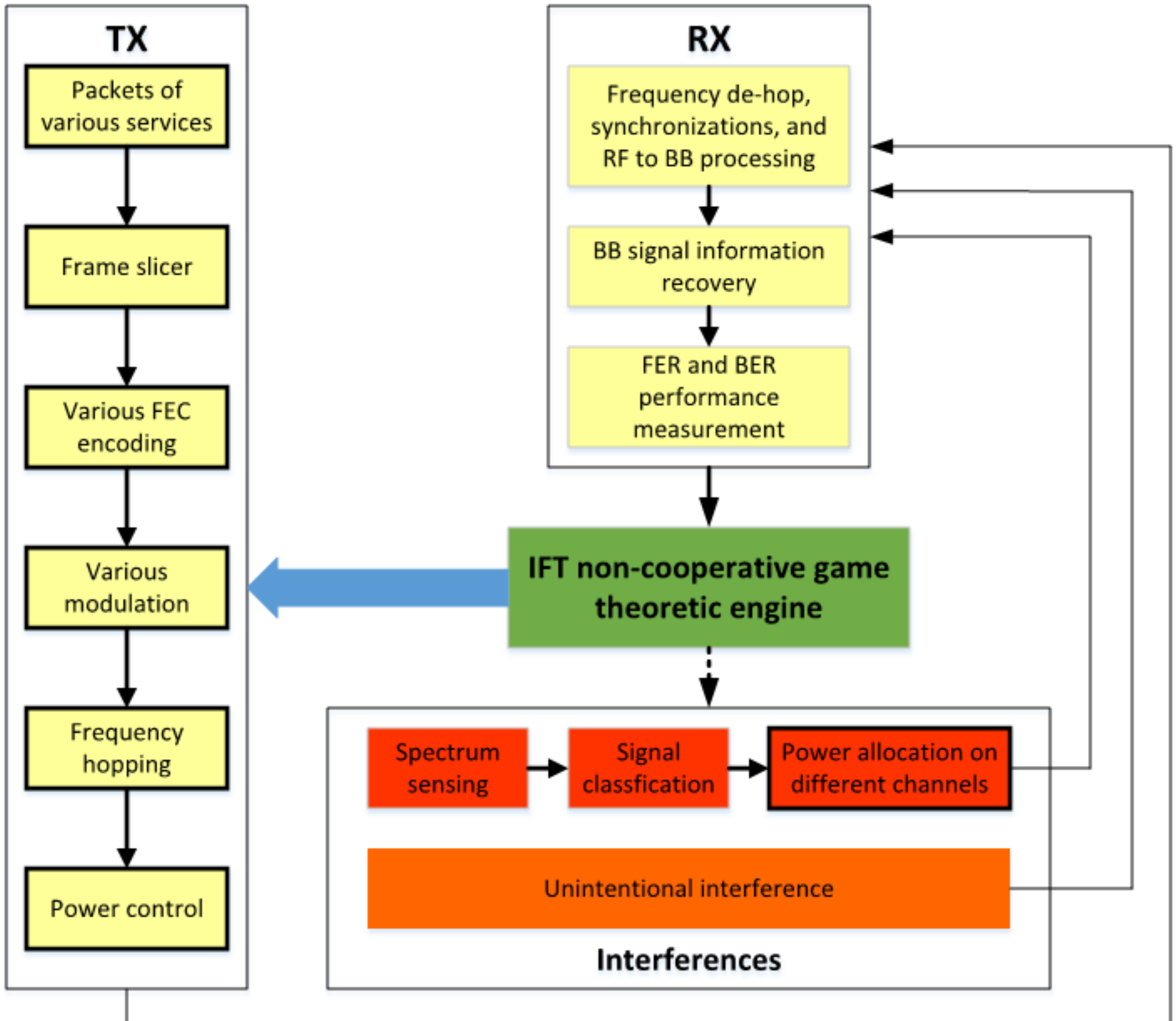
Proposed Game DRA (1)

- Game model for the trade-off studies of power controls, modcods, LPI, LPD, and channel efficiency

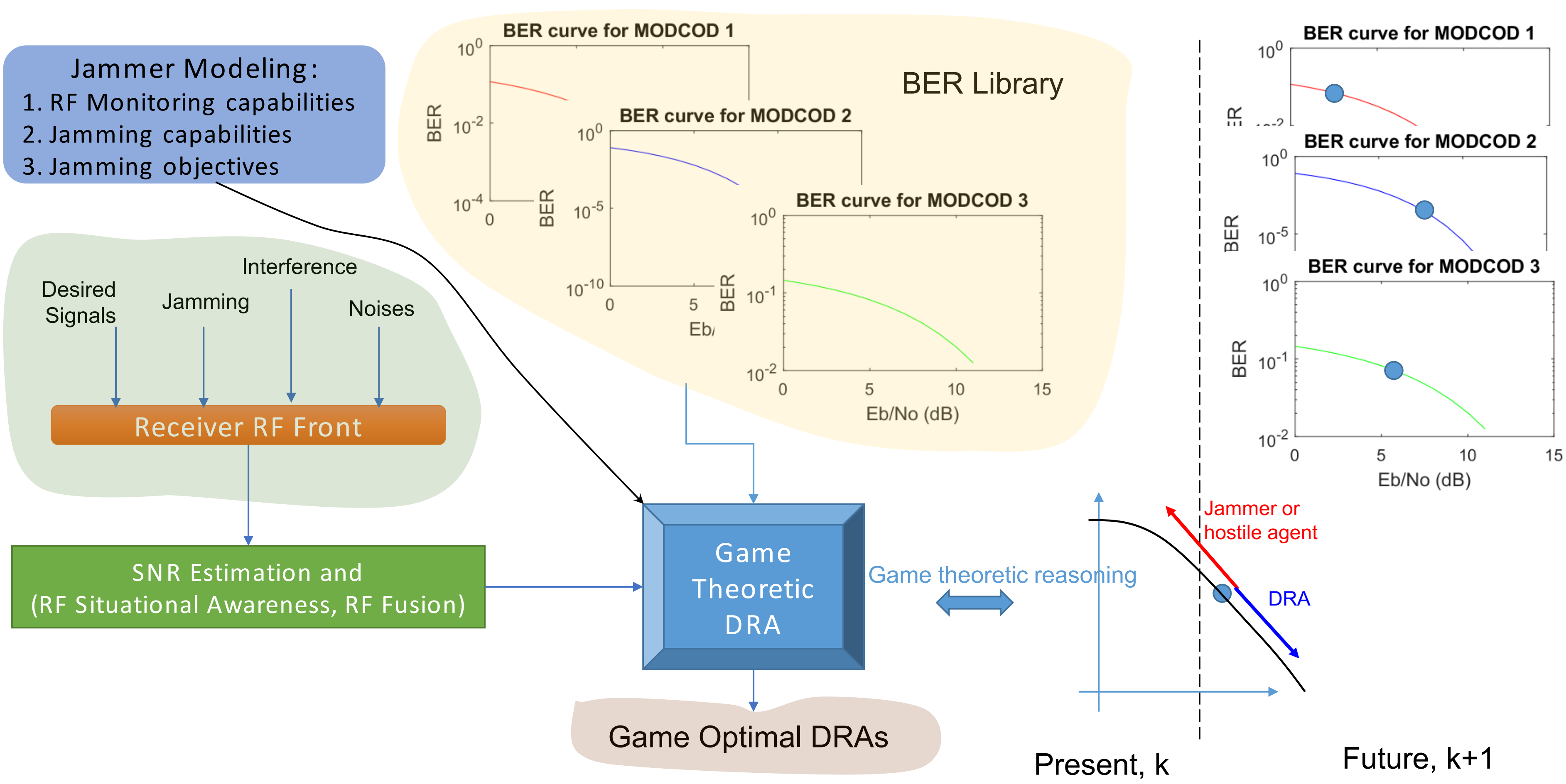


Proposed Game DRA (2)





Proposed Game DRA (3)



Utility Function of Transmission Pair

FER-E_b/N_0 curves

$$U = \sum_{n=0}^{N-1} r\log_2 M \left[1 - FER\left(\frac{P_{r,n}}{N_0 + I_{r,n}}, (\mathrm{M}, \mathrm{r}, \mathrm{L})\right)\right] - \sum_{n=0}^{N-1} Cost \cdot P_{t,n}$$

Effective rate

Transmission cost

- r: Channel coding rate
- M: M-ary modulation scheme
- L: frame length
- $(M, \mathrm{r}, \mathrm{L})$ is a tuple which belongs to different waveform with specified frame length
- $SINR_{\mathrm{n}}$: the receiver side of the transmission pair, $SINR_n = \frac{P_{r,n}}{N_0 + I_{r,n}}$ where $I_{r,\mathrm{n}}$ is the received power from the jammer, $P_{r,n}$ is the received signal power at the receiver side of the transmission pair and N_0 is the additive Gaussian white noise.
- $P_{t,\mathrm{n}}$: transmission power of the transmission pair
- n: the channel that the transmission pair is using
- $Cost$: the transmission price for power
- $FER(SINR)$: frame error rate for a certain $SINR$, which can be obtained from the FER-E_b/N_0 curves. $FER(SINR)$ makes our model practical and general.

Utility Function of Jammer

$$U_{jammer} = -\sum_{n} r\log_2 M\left[1 - FER\left(\frac{P_{r,n}}{N_0 + I_{r,n}}, (\mathrm{M}, \mathrm{r}, L)\right)\right] - \sum_{n} Cost_{jammer} \cdot I_{t,n}$$

FER-E_b/N_0 curves

Effective rate

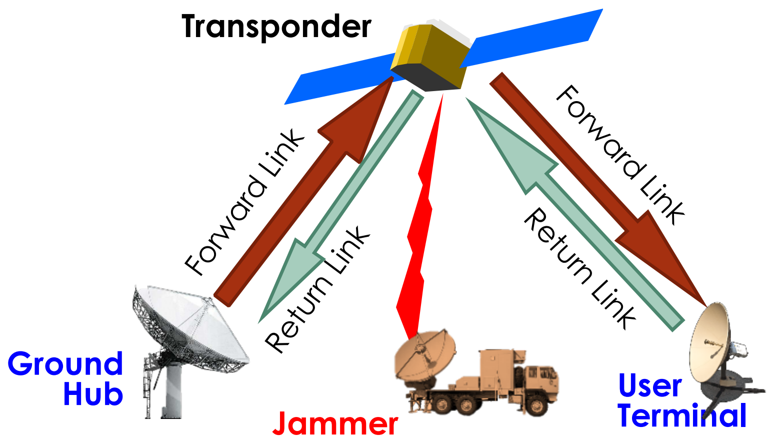
Transmission cost

where $I_{t,n}$ is the transmit power of the jammer on channel n,
$Cost_{jammer}$ is the unit cost for the jammer's transmit power.

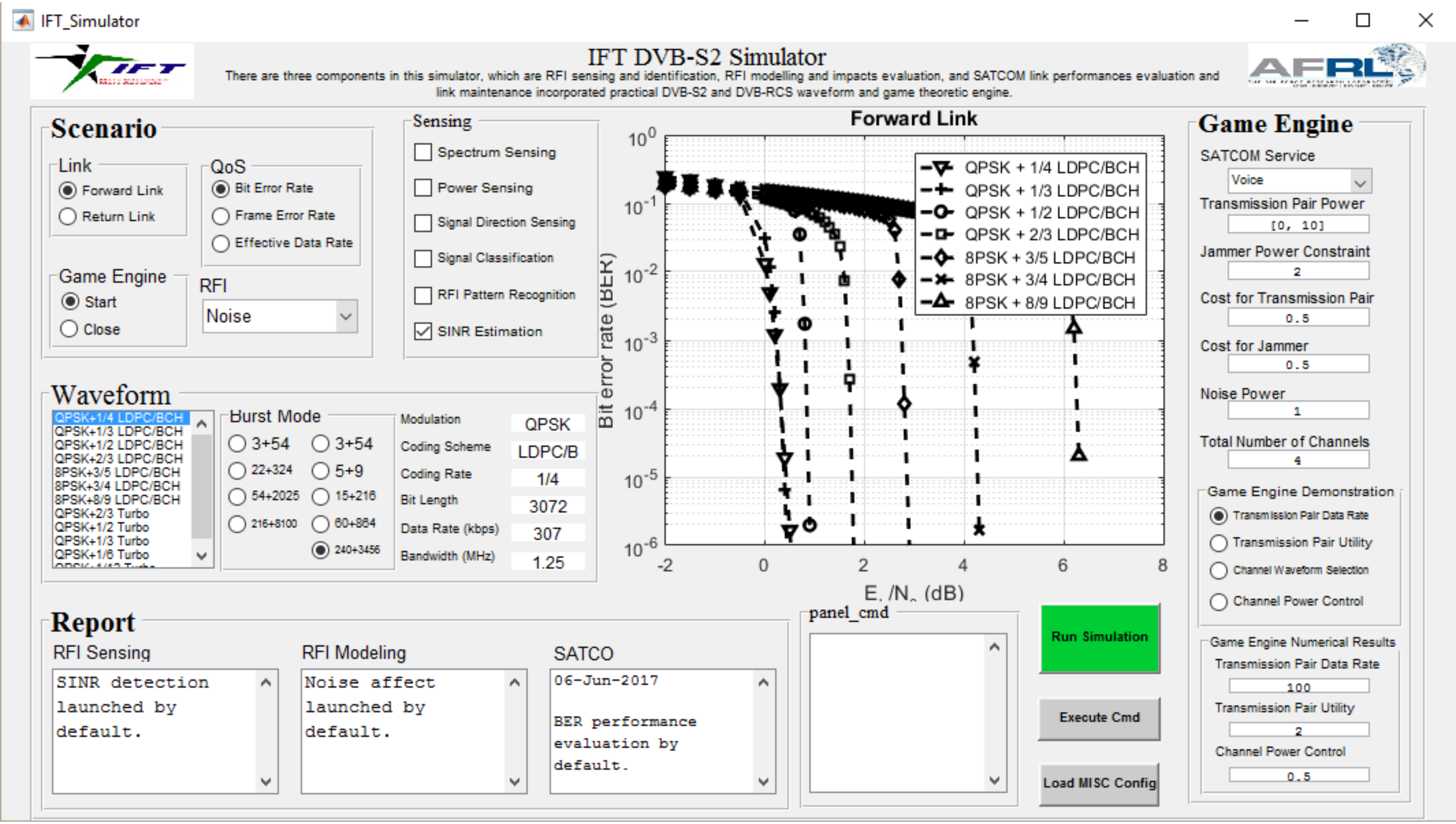
$$U_{jammer} = \sum_{n} r\log_2 M\left[FER\left(\frac{P_{r,n}}{N_0 + I_{r,n}}, (\mathrm{M}, \mathrm{r}, L)\right)\right] - \sum_{n} Cost_{jammer} \cdot I_{t,n}$$

Research Scenario

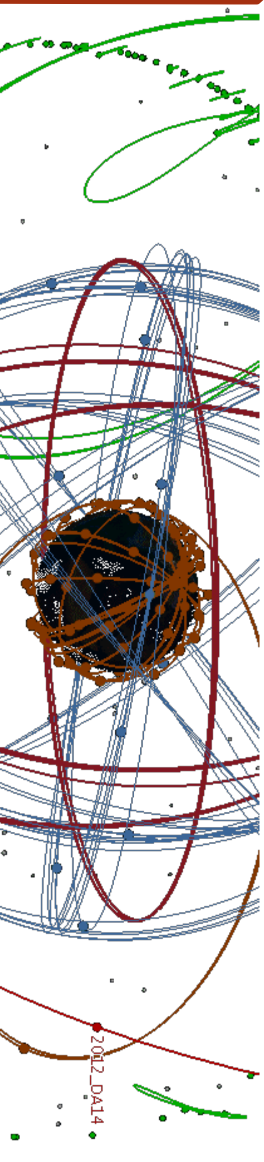
- DVB-S2 Waveforms
- Transpondered return links



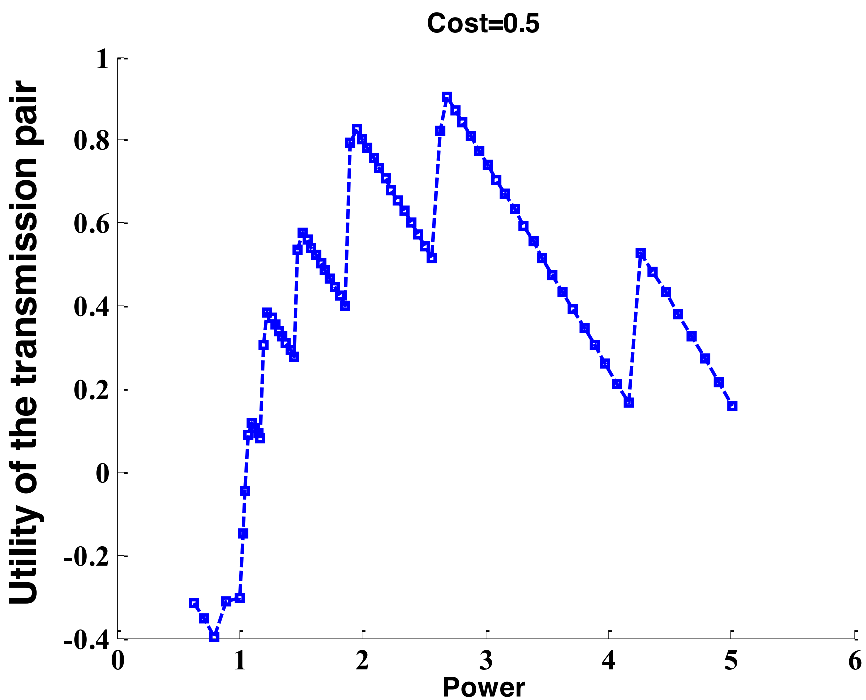
DVB-S2 Simulator



Power vs Utility



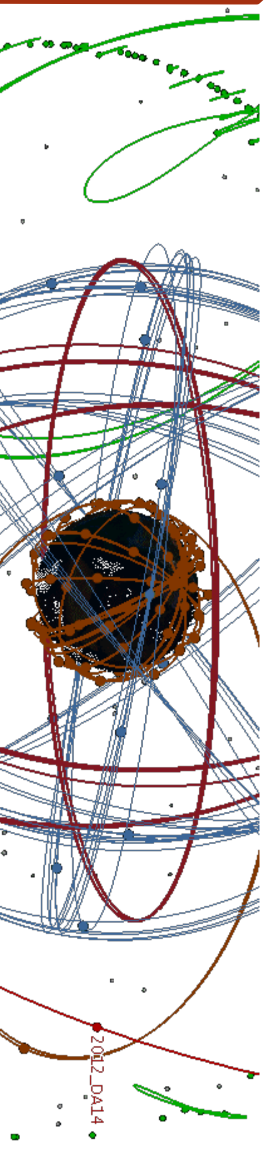
- For a given jamming and noise power (=1w)
- For each power level, we choose the MODCOD with maximum utility from 7 DBV-S2 waveforms:

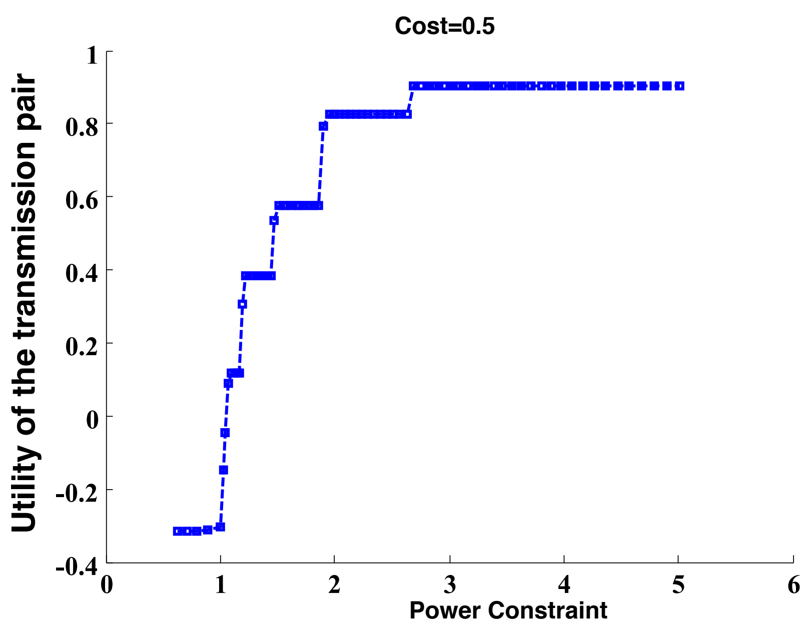


1. QPSK+1/4 LDPC/BCH,
2. QPSK+1/3 LDPC/BCH,
3. QPSK+1/2 LDPC/BCH,
4. QPSK+2/3 LDPC/BCH,
5. 8PSK+3/5 LDPC/BCH,
6. 8PSK+3/4 LDPC/BCH,
7. 8PSK+8/9 LDPC/BCH.

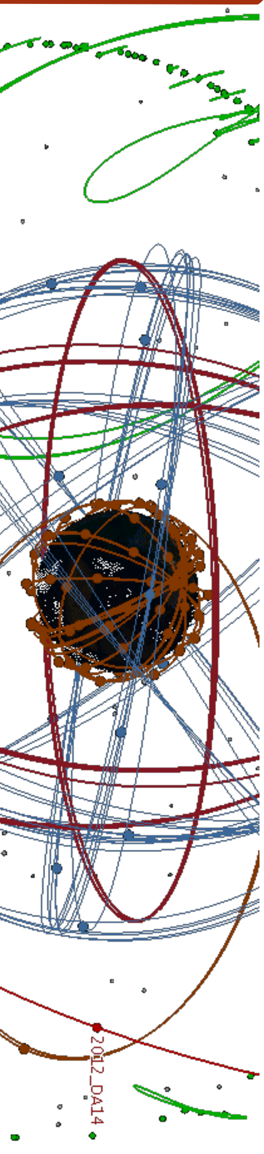
Power Constraints vs Utility

- For a given jamming and noise power (=1w)
- For each power constraint level, we pick the maximum values from all the power less than the constraint.

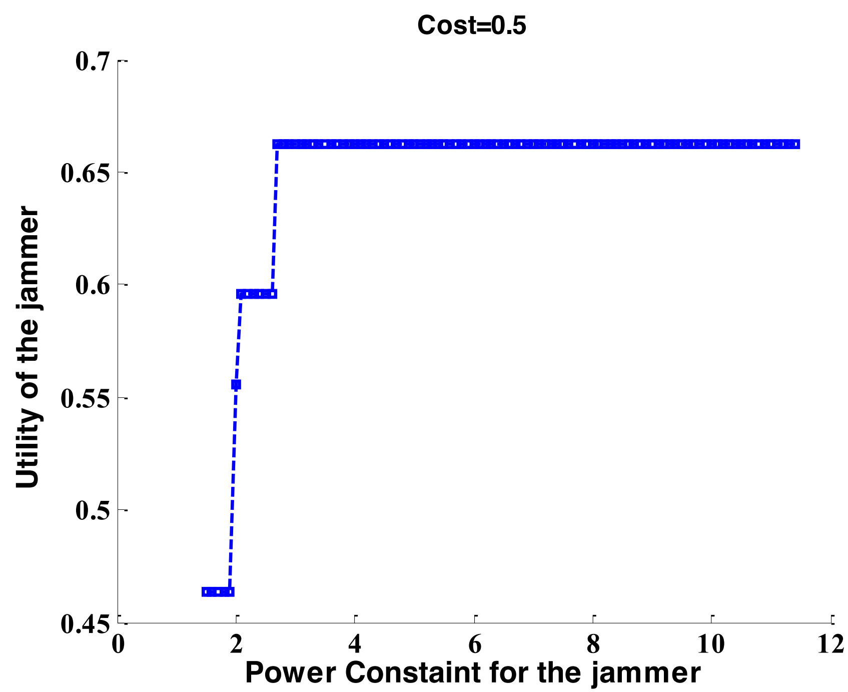




Power Constraints vs Jammer Utility

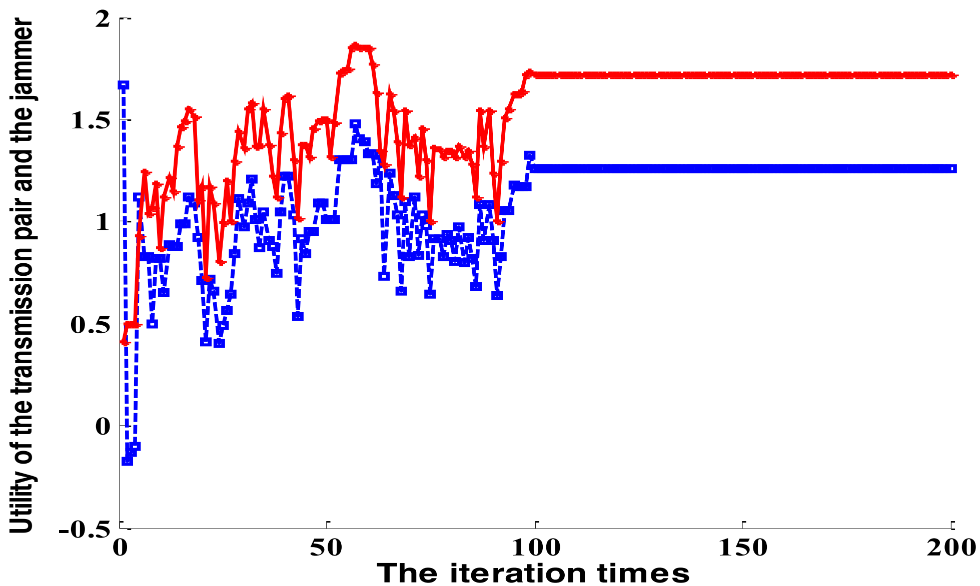


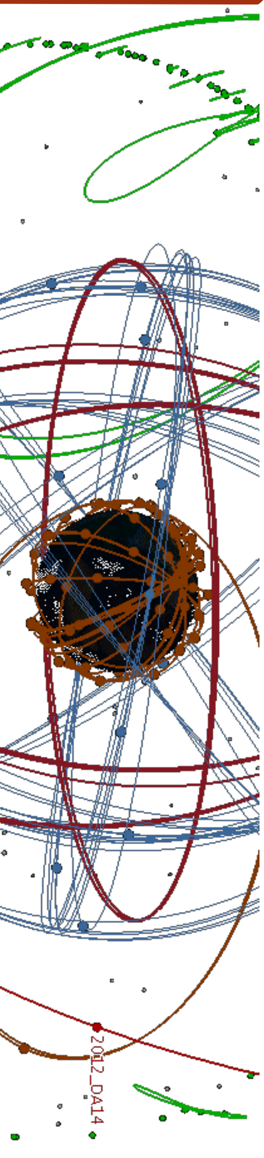
- For a given noise power (0.2w)
- For a given transmission setup: 4 channel with 1w each, QPSK +1/2 LDPC/BCH



Game Solution

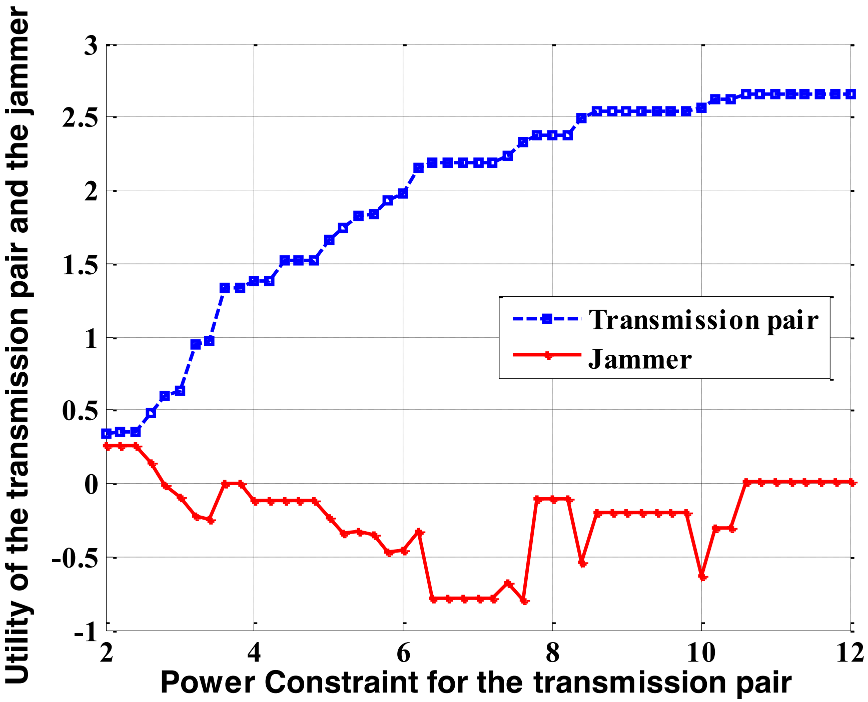
- Fictitious play concept:
  - each player presumes that the opponents are playing stationary.
  - each player thus best responds to the empirical frequency of play of their opponent.

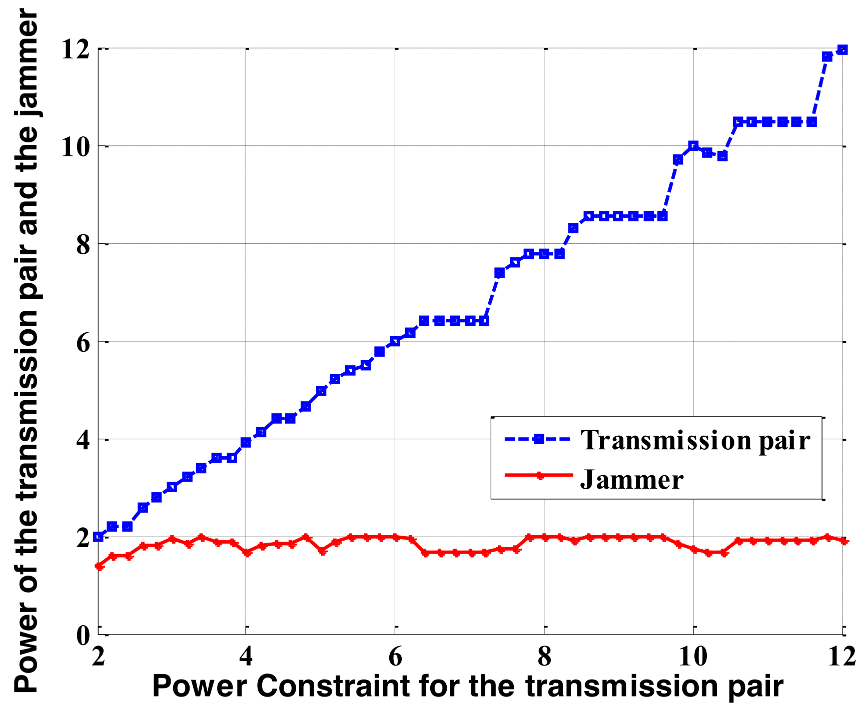




User Case 1

- Cheap Transmission/Jamming Power





The relationship between the Utility/ Power and the transmission pair power constraint four channels case (Qcon=2, $cost_p = cost_j$ =0, Pcon=[2 12], N_0=0.2)

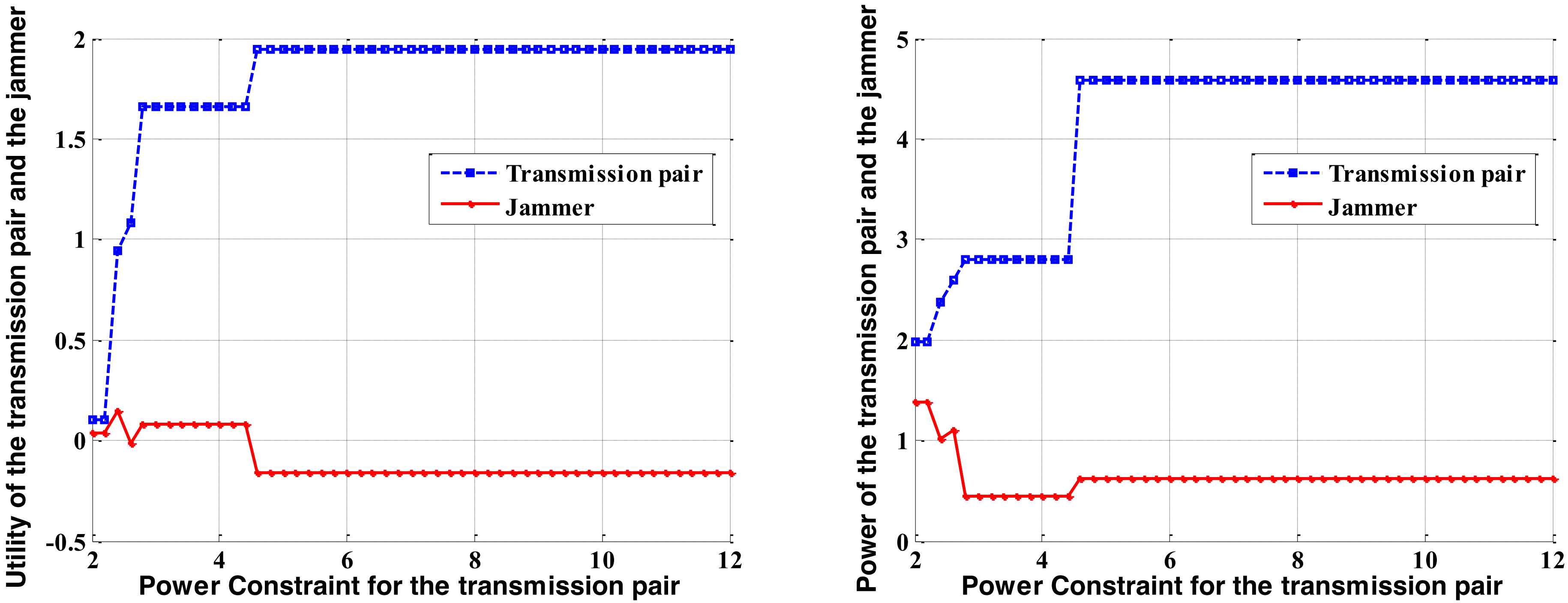
Jamming power constraint

Power cost per w

Transmission power constraint

User Case 2

- Expensive Transmission/Jamming Power



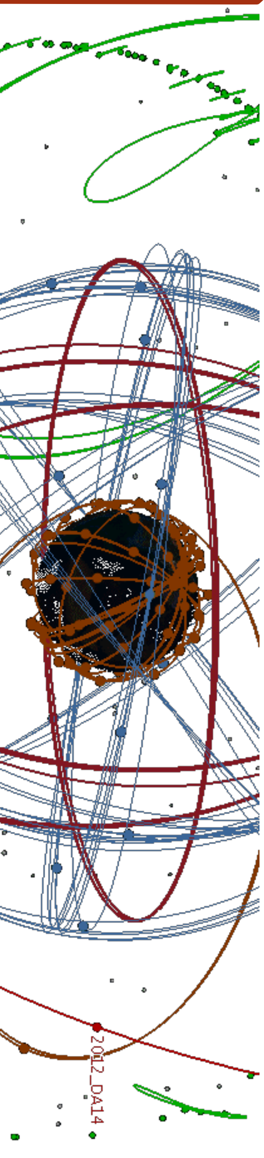
The relationship between the Utility/ Power and the transmission pair power constraint four channels case (Qcon=2, $cost_p = cost_j$ =0.5, Pcon=[2 12], N_0=0.2)

Jamming power constraint

Power cost per w

Transmission power constraint

Conclusions



- Developed a game theoretic DRA approach for anti-jamming in the presence of smart jammers.
- The SATCOM system is abstracted by a series of FER curves, along which blue side (SATCOM) and red side (smart jammer) are playing a dynamic DRA game.
- The game model considers both power management and MODCODs
- We developed a simulator to executive the game DRA strategies.
- the future, we will consider more realistic constraints, spectrum sensing, and asymmetric information structures of the game model

Questions and Comments?