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



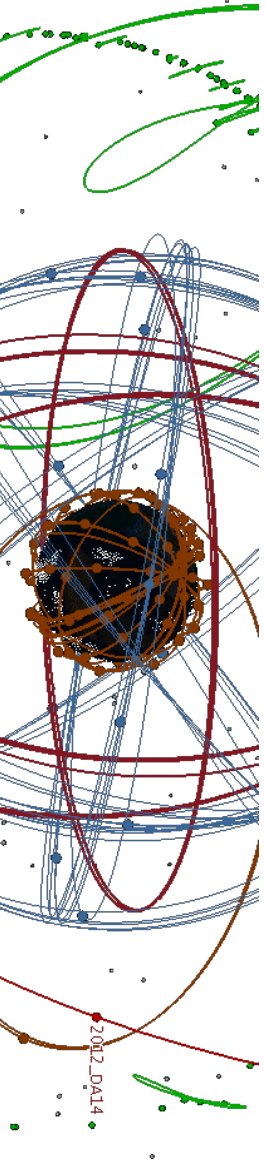
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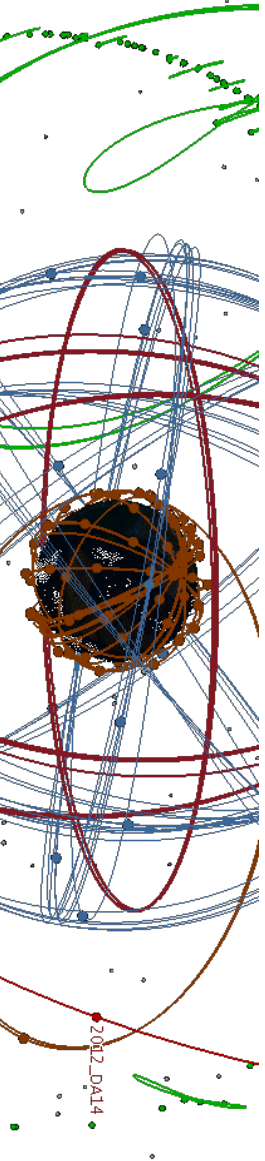
Outline

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



Introduction

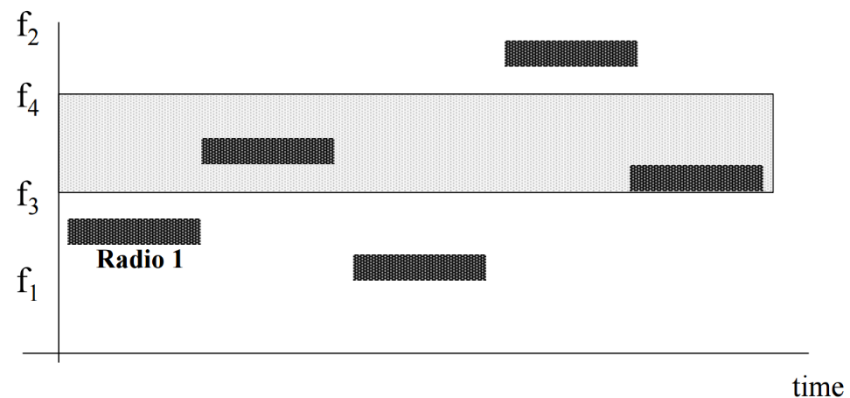
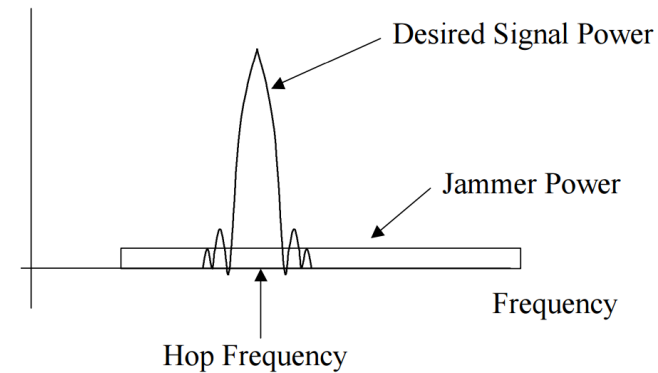
- ▶ **Jamming:** Intentional RF interference to harm wireless communications.
- ▶ As technology advances, adversaries have increasingly **sophisticated capabilities** to jam transmissions over satellites.
- ▶ There are several types of jamming for wireless communication
 - ▶ Proactive jammer
 - ▶ Reactive 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

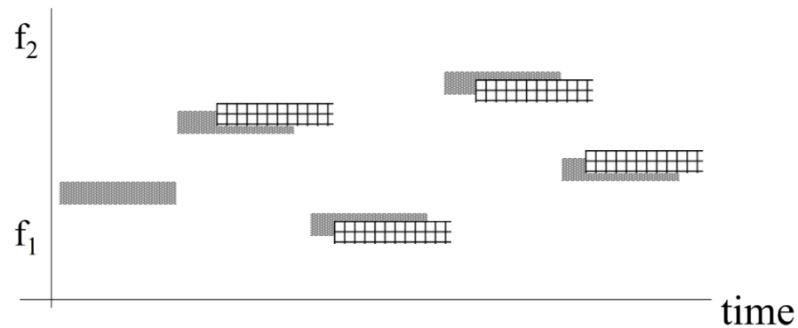
- FHSS for Partial Band Jamming
 - The partial band jammer can cause more problems for uncoded transmission of FHSS



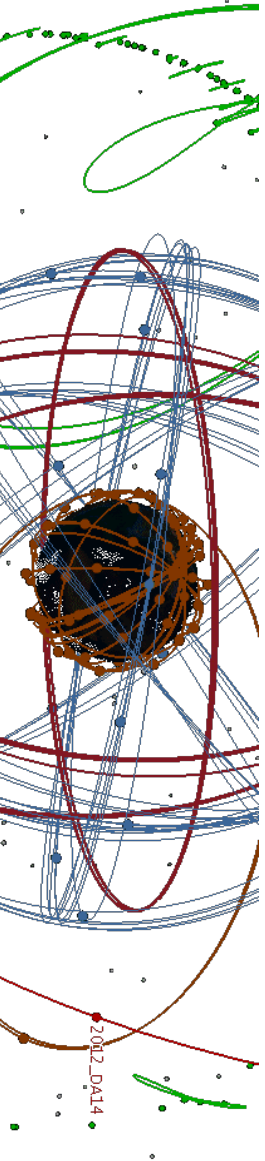
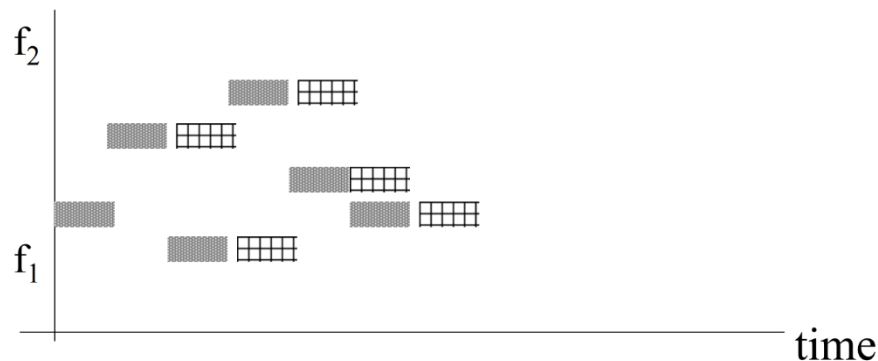
FHSS for Hostile Jamming (2)

► FHSS for Follow-along Jamming

- Jammer monitors the transmitted signals and concentrates all power in that band

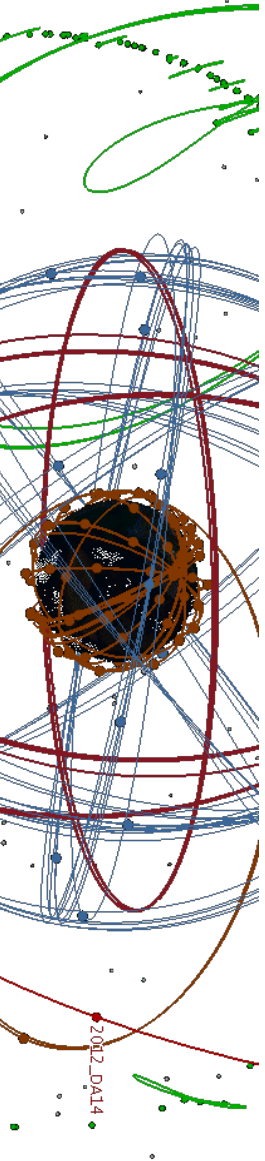


- FHSS can either hops faster than the jammer can adapt to mitigate the follow-along jamming



Game Theory

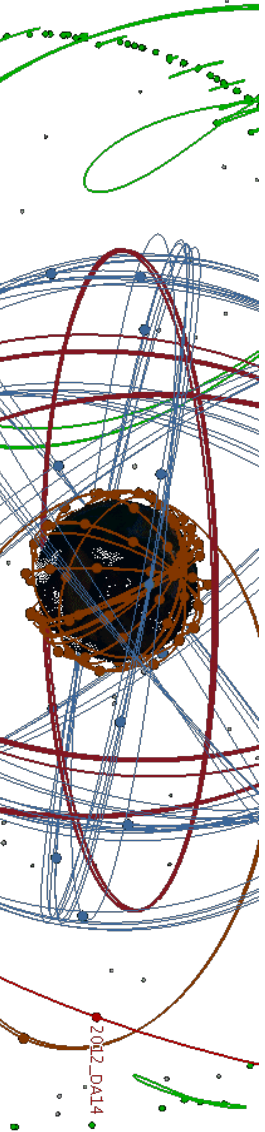
- ▶ ... is a mathematical framework to model and analyze conflicts among a group of entities
 - ▶ Each entity is called a player.
 - ▶ The system states depend on the **joint** control of all players.
 - ▶ The interest of a player is usually modelled by a cost/utility/payoff function.
 - ▶ The equilibrium 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.

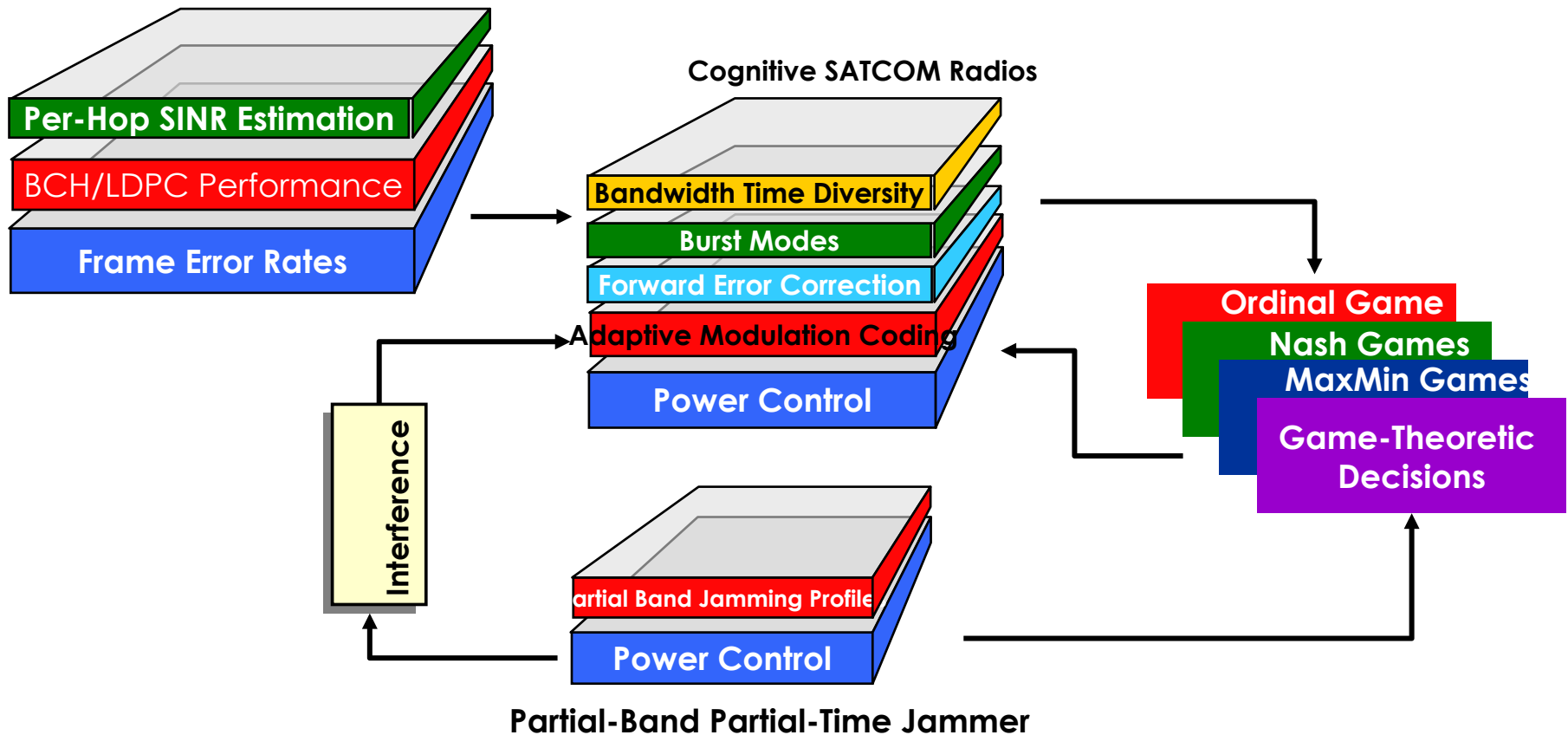
| OSI Layer | Application field | Specific application |
|------------------|-----------------------|--|
| Physical | Power control | Power control for CDMA Power management in MIMO |
| Data link | Medium access control | Access to slotted Aloha, random access to the interference channel |
| Network | 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 |



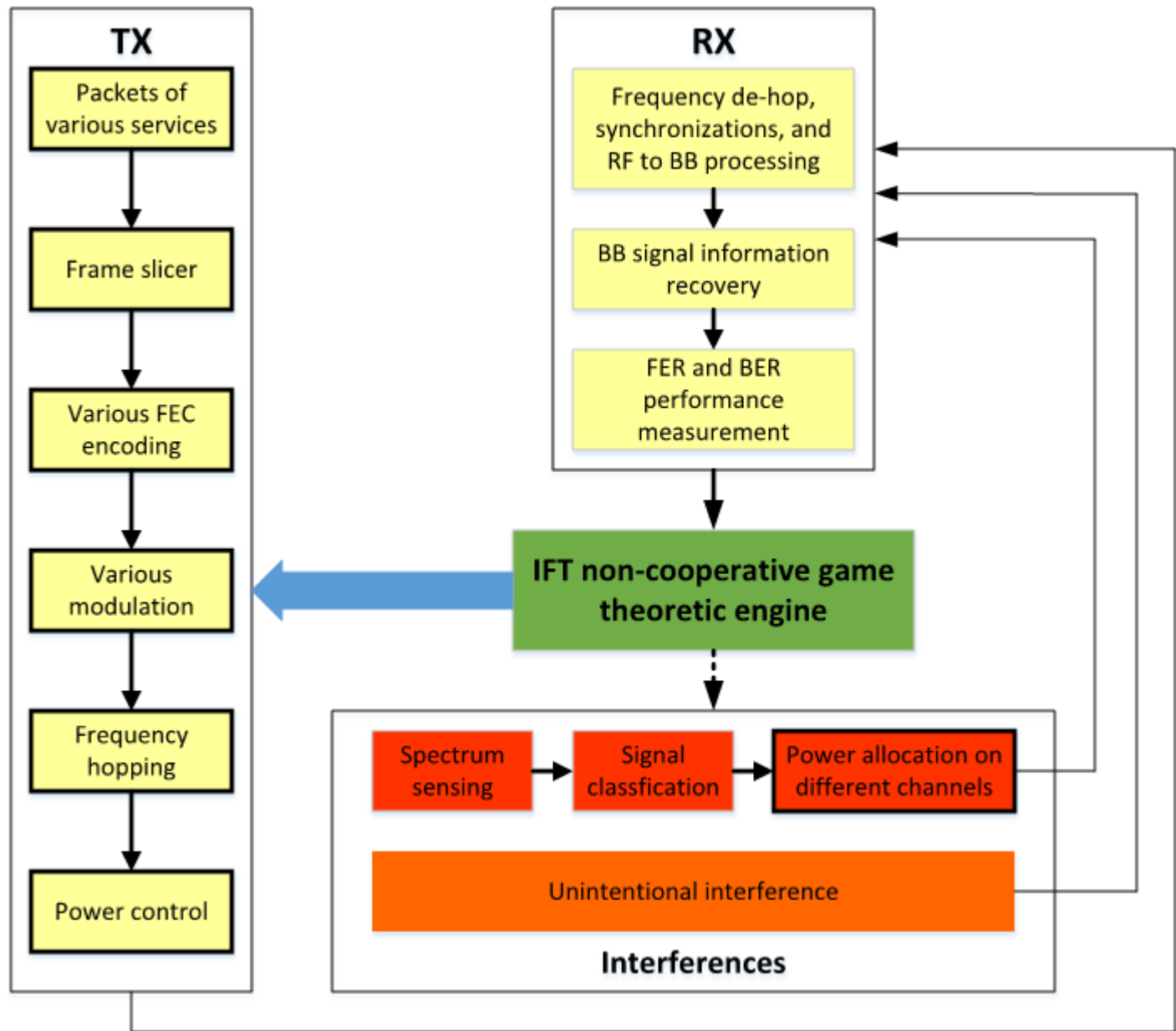
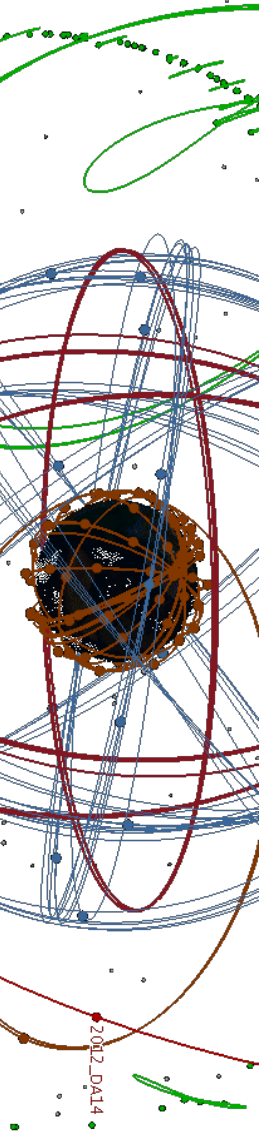
Proposed Game DRA (1)

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



Proposed Game DRA (2)

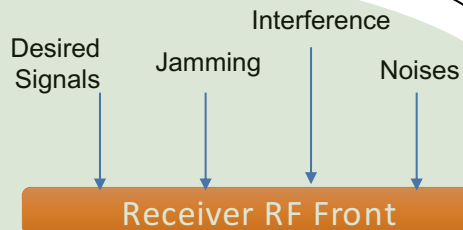
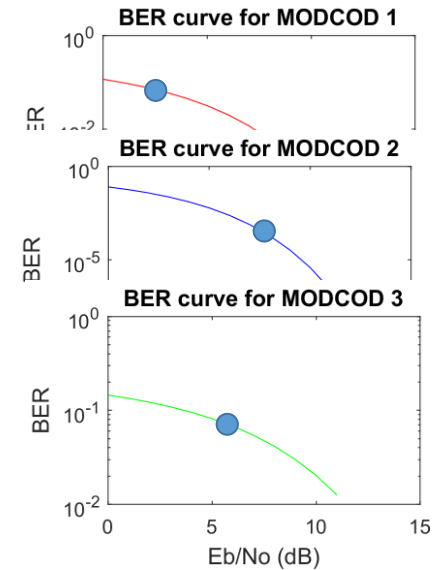
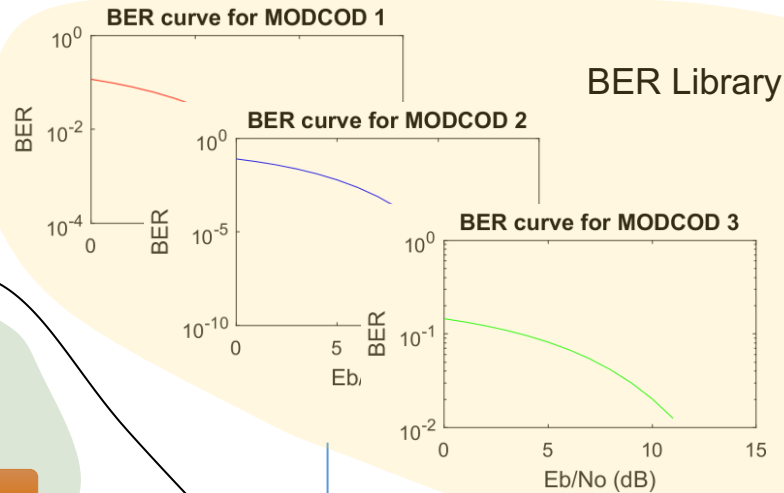
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Proposed Game DRA (3)

Jammer Modeling:

1. RF Monitoring capabilities
2. Jamming capabilities
3. Jamming objectives

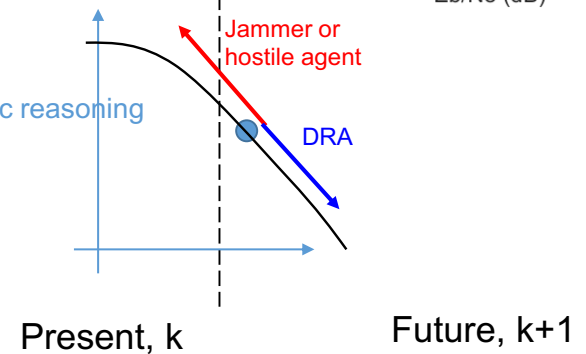


SNR Estimation and
(RF Situational Awareness, RF Fusion)

Game
Theoretic
DRA

Game theoretic reasoning

Game Optimal DRAs



Utility Function of Transmission Pair

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

Effective rate
Transmission cost

FER- E_b/N_0 curves

- r : Channel coding rate
- M : M -ary modulation scheme
- L : frame length
- (M, r, L) is a tuple which belongs to different waveform with specified frame length
- $SINR_n$: the receiver side of the transmission pair, $SINR_n = \frac{P_{r,n}}{N_0 + I_{r,n}}$ where $I_{r,n}$ 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.
- $P_{t,n}$: 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

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

Effective rate
Transmission cost

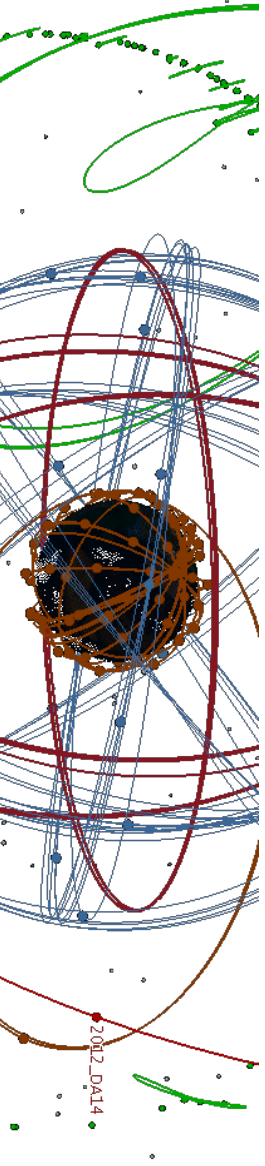
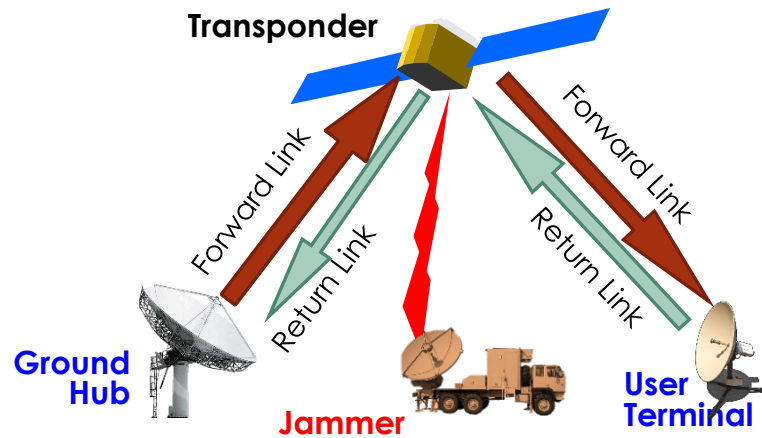
FER- E_b/N_0 curves

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.

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

Research Scenario

- ▶ DVB-S2 Waveforms
- ▶ Transpondered return links



DVB-S2 Simulator

IFT_Simulator

IFT DVB-S2 Simulator

There are three components in this simulator, which are RFI sensing and identification, RFI modelling and impacts evaluation, and SATCOM link performances evaluation and link maintenance incorporated practical DVB-S2 and DVB-RCS waveform and game theoretic engine.

AFRL

Scenario

Link

Forward Link
 Return Link

QoS

Bit Error Rate
 Frame Error Rate
 Effective Data Rate

Game Engine

Start
 Close

RFI

Noise

Sensing

Spectrum Sensing
 Power Sensing
 Signal Direction Sensing
 Signal Classification
 RFI Pattern Recognition
 SINR Estimation

Forward Link

Bit error rate (BER) vs E_b/N_0 (dB) plot for various configurations:

- QPSK + 1/4 LDPC/BCH
- QPSK + 1/3 LDPC/BCH
- QPSK + 1/2 LDPC/BCH
- QPSK + 2/3 LDPC/BCH
- 8PSK + 3/5 LDPC/BCH
- 8PSK + 3/4 LDPC/BCH
- 8PSK + 8/9 LDPC/BCH

Game Engine

SATCOM Service: Voice

Transmission Pair Power: [0, 10]

Jammer Power Constraint: 2

Cost for Transmission Pair: 0.5

Cost for Jammer: 0.5

Noise Power: 1

Total Number of Channels: 4

Game Engine Demonstration

Transmission Pair Data Rate
 Transmission Pair Utility
 Channel Waveform Selection
 Channel Power Control

Game Engine Numerical Results

Transmission Pair Data Rate: 100
Transmission Pair Utility: 2
Channel Power Control: 0.5

Waveform

QPSK+1/4 LDPC/BCH

Burst Mode: 3+54 3+54 22+324 5+9 54+2025 15+216 216+8100 60+884 240+3456

Modulation: QPSK
Coding Scheme: LDPC/B
Coding Rate: 1/4
Bit Length: 3072
Data Rate (kbps): 307
Bandwidth (MHz): 1.25

Report

RFI Sensing: SINR detection launched by default.

RFI Modeling: Noise affect launched by default.

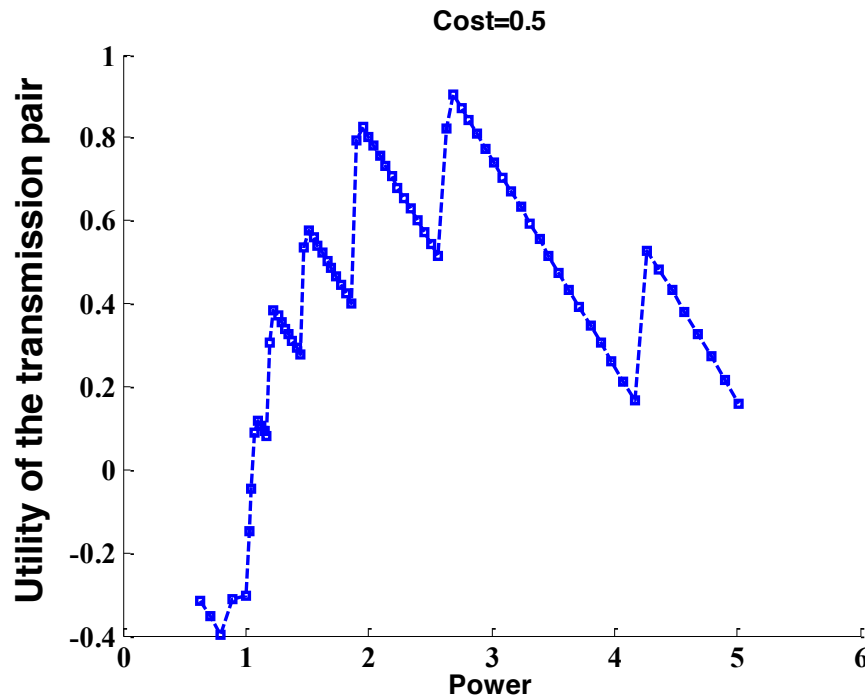
SATCO: 06-Jun-2017
BER performance evaluation by default.

panel_cmd

Run Simulation (Green button)
Execute Cmd (Grey button)
Load MISC Config (Grey button)

Power vs Utility

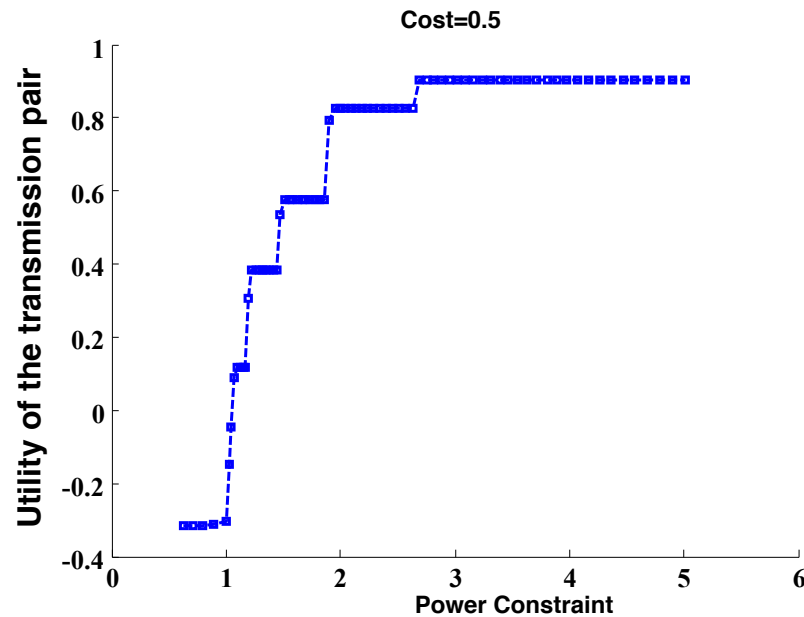
- ▶ For a given jamming and noise power ($=1\text{w}$)
- ▶ For each power level, we choose the MODCOD with maximum utility from 7 DBV-S2 waveforms:



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.

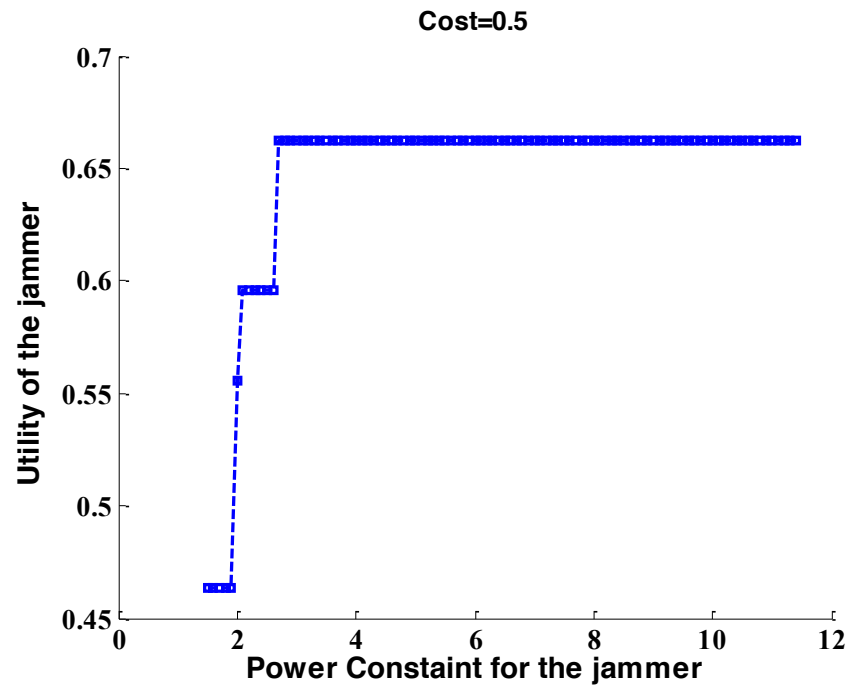
Power Constraints vs Utility

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



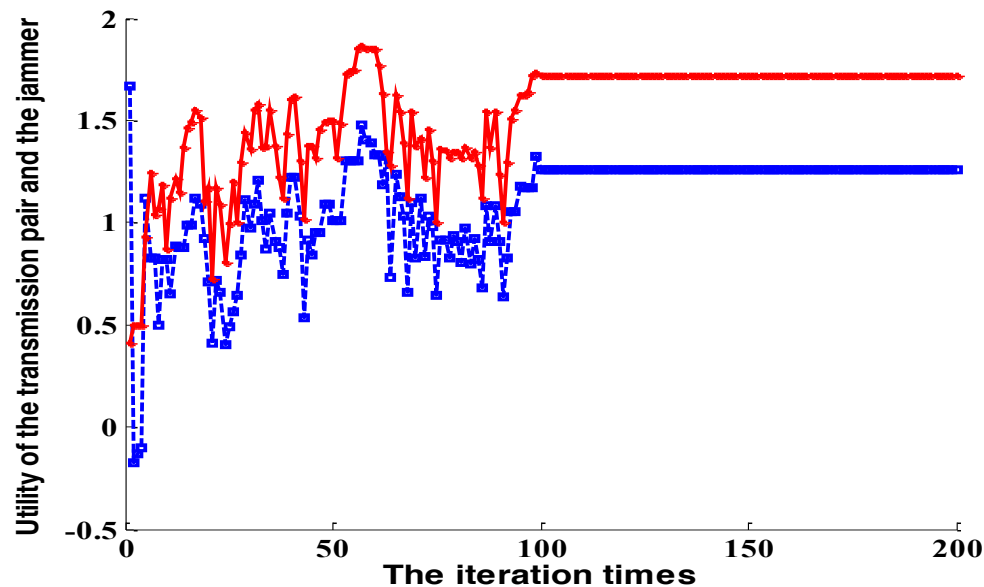
Power Constraints vs Jammer Utility

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



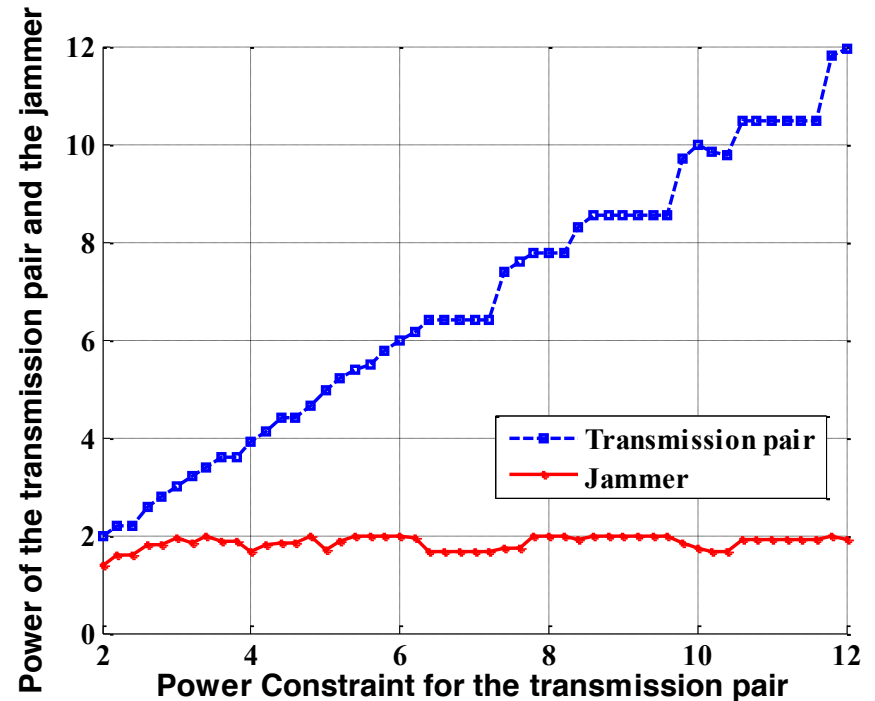
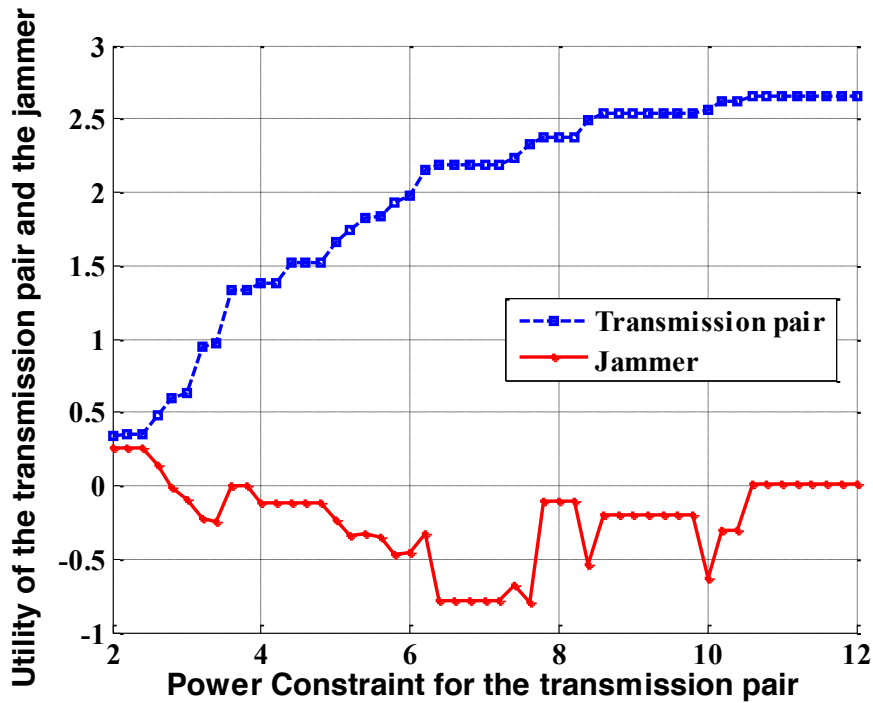
Game Solution

- ▶ 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 ($Q_{con}=2$, $cost_p = cost_j = 0$, $P_{con}=[2 \ 12]$, $N_0=0.2$)

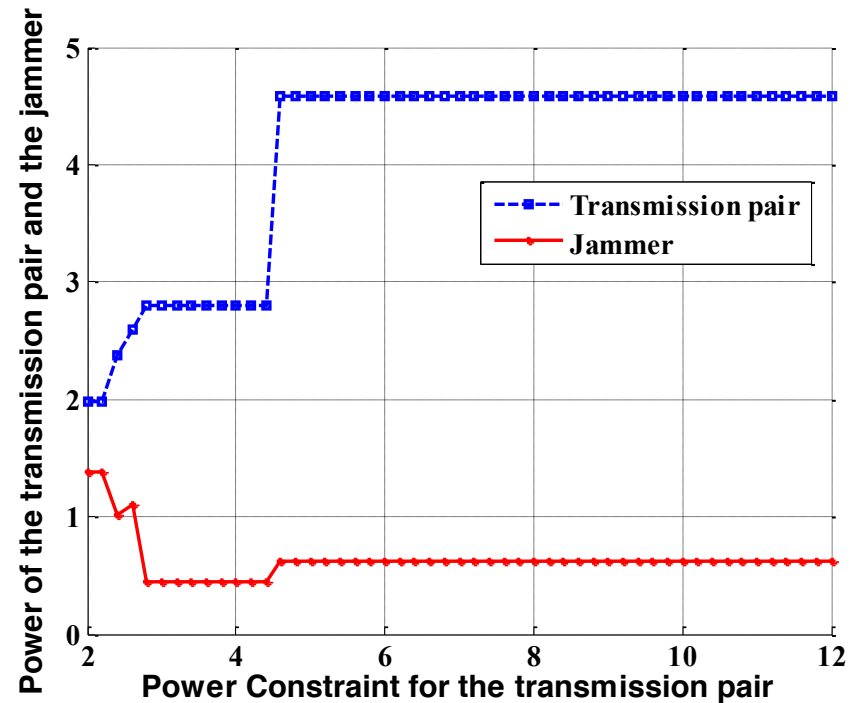
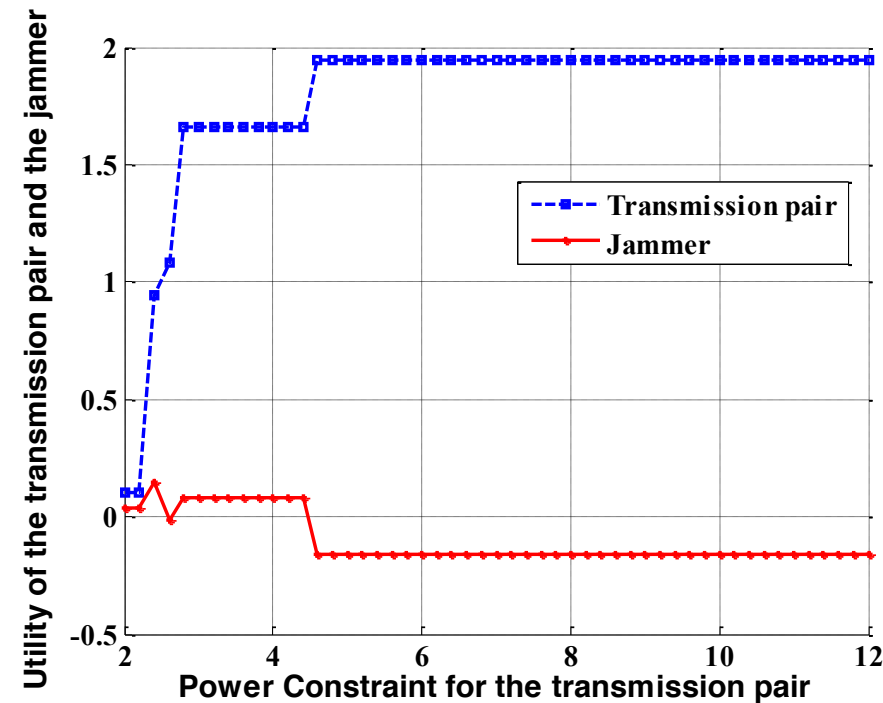
Jamming power constraint

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 ($Q_{con}=2$, $cost_p = cost_j = 0.5$, $P_{con}=[2 \ 12]$, $N_0=0.2$)

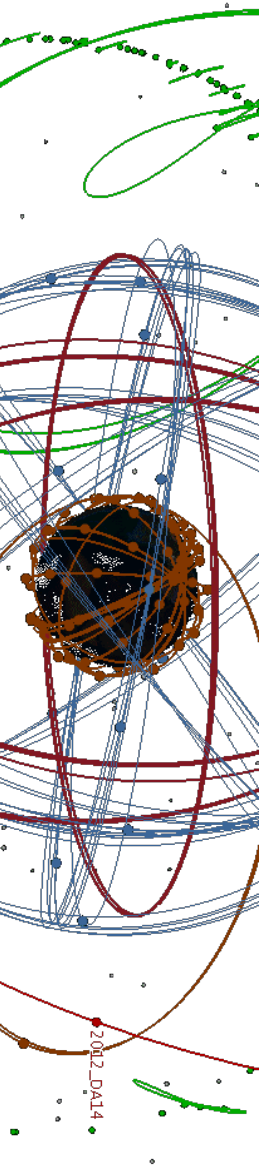
Jamming power constraint

Power cost per w

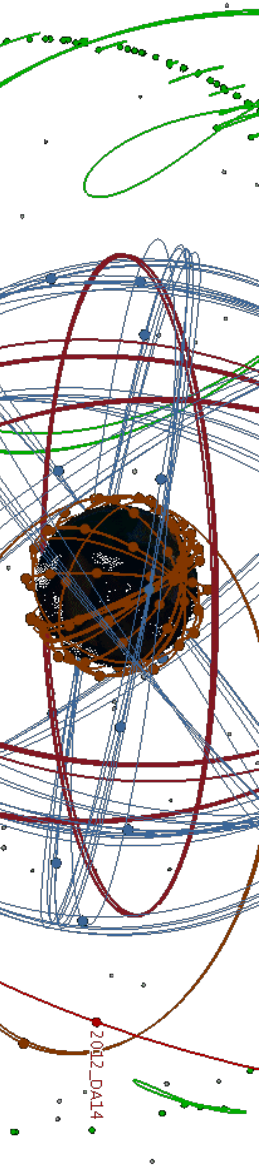
Transmission power constraint

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?



Thank You!