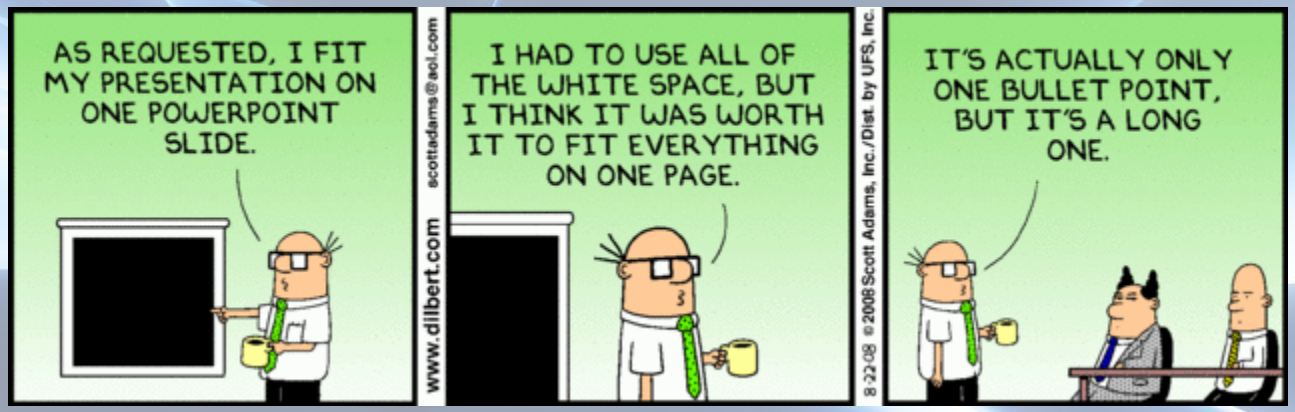
Good Morning



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Transformation through Information in Cyberspace

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Information and Cyberspace Symposium, Leavenworth, KS, Sep 22-26, 2008

My Background

Information Processing

- Detection and Estimation theory
- Control theory
- Optimization and Decision Theory
- Information/Communication Theory

Applied to Wireless Communications, Radar signal processing as well as distributed sensor networks

Ten Skills for Cyber Warriors: Prob and Stats, Change Detection, Pattern analysis, Temporal analysis, Link Analysis, Spatial analysis, modeling and simulation, clustering, decision making, data mining.

Cyberspace

Definition: Cyberspace is a domain characterized by the use of **electronics** and the **electromagnetic spectrum** to store, modify, and exchange **data** via **networked** systems and associated physical infrastructures

- Definition recognizes cyberspace is more than just computer networks
- Cyberspace is a war fighting domain without borders!
- ***Anything we can do can be done to us***
- ***Embracing Technology will help us be one step ahead in protecting our information/operations***

Information

- ***Information is Power*** – both on offense and defense
- Backbone of Cyberspace domain
  - Freedom to use and reliably share and process information
  - Preventing others from using the domain/information to hurt us
- Two fundamental aspects
  - Share Information successfully (Communication systems/theory)
  - Process Information to help make decisions (Signal processing and Control) and learn
- Key operation – Situational/Battlespace Awareness

Sense/Observe → Decide → Act → Learn

Awareness and Intelligent use of EMS is critical

Securing the EMS?

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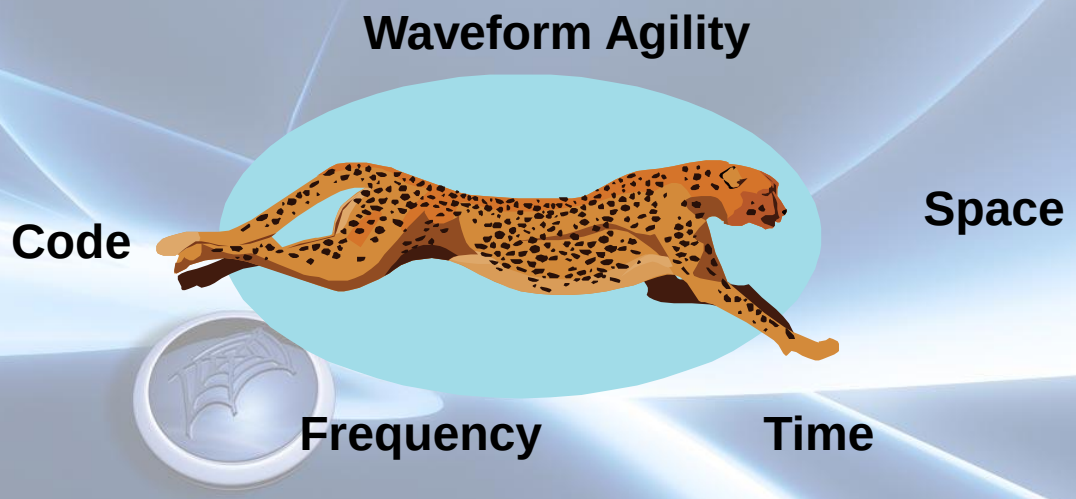
Degrees of Freedom

- For effective/survivable communication, we need to exploit multiple degrees of freedom
- Denial/Attack should also be along multiple dimensions



- Outcomes
  - Increase capacity, reliability and performance
  - Improve our capability to deal with jamming and operate in hostile environments

Waveform Agility (1/5)

- Spread spectrum waveforms are primary candidates for LPI and LPD

Design of complex (polyphase) spreading sequences for direct sequence and multi-carrier CDMA waveforms with custom, adaptible correlation properties

Sponsor: NSF

Key Contributions: Fundamental limits on the aperiodic mean square correlation properties of polyphase spreading sequences; A novel viterbi approach (low complexity) to code design (2 –patents filed); evolutionary approaches.

Impact LPI; Spectrum agility for next generation radio; ability to adapt to jammers; ability to design codes with specific properties; Radar pulse compression; Multi-beam radar applications

Exploiting the "Code" dimension

Waveform Agility (2/5)

Design and analysis of Frequency hopping sequences for CDMA and OFDMA waveforms based on the Residue Number system Arithmetic

Contributions: The construction of FH patterns is based on RNS arithmetic, resulting in patterns which are

(1) Orthogonal within a cell -- minimize intra-cell interference.

(2) Intersect only once from cell to cell – reduced inter-cell interference.

(3) Engaging users hop to a frequency far from the previous one – users can occupy the whole bandwidth within a small fraction of total time slots.

Impact A new robust/scalable high performance solution for Frequency agile radios

Exploiting the "Frequency" dimension

Waveform Agility (3/5)

Use of non-contiguous transmission bands with ability to hop and adapt to external conditions (jamming, interference etc.) is desirable

Design and analysis of a common multi-carrier framework for a single carrier modulation schemes based on truncated Fourier series approximations of pulse/chip shapes

Sponsor – NSF

Impact – Novel SDR architecture for waveform design. Methods of dealing with Jamming, impulse noise and high PAPR in multi-carrier modulated systems.

Exploiting the "Frequency" dimension

Waveform Agility (4/5)

- **Multi-antenna (MIMO) systems and associated signal processing enable**
  - **Increase in capacity**
  - **Improvement in QoS (BER Performance)**
  - **Beamforming**
- **Targeted jamming applications (directed energy weapons)**
- **Spatial tracking**
- **Intelligent MIMO systems for situation based operation**

Design of Redundant Residue Number System based space time codes for MIMO systems

Exploiting the "Space" dimension

Waveform Agility (5/5)

- **Situational awareness of EMS starts with sensing and opportunistic use of the spectrum and/or preventing use by our adversaries**
- **Technical developments in the realm of Cognitive Radio Networks can play a direct role in dynamic spectrum management**

- **What is a Cognitive Radio Network?**

- **Research at K-State is focused on:**
  - **Design of Practical Cognitive radio via a dedicated spectrum sensing architecture**
  - **Developing algorithms to enable optimal spectrum sharing among users**
  - **Traffic modeling and prediction in a cognitive radio network**

Exploiting the "Time" dimension

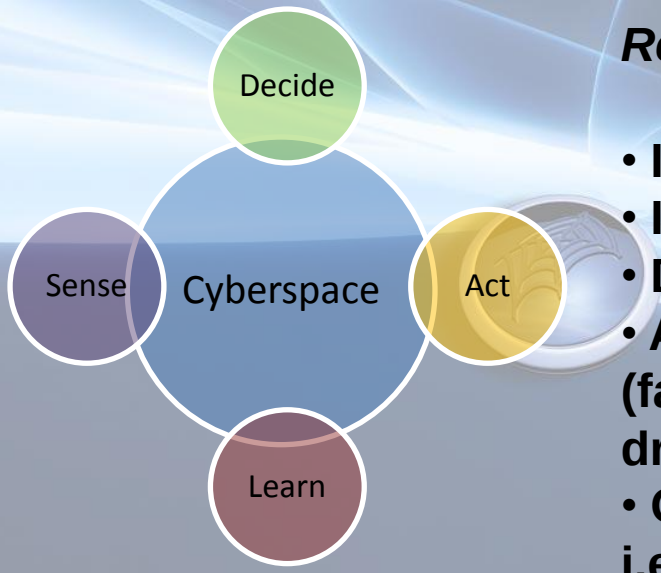
Other Things to Consider

- **Protecting GPS and positioning capability (ongoing work with Sandia National Labs)**
- **Attacking navigational capabilities of others**
- **Ability to setup and destroy communication infrastructure**
- **Dominating the EMS with capabilities that are constantly evolving**

Information

Real Time Electronic Battlefield Vision

- **Sensors, UAVs, Autonomous Robots, decision makers and actuators (maybe shooters) are networked together via Cyberspace**



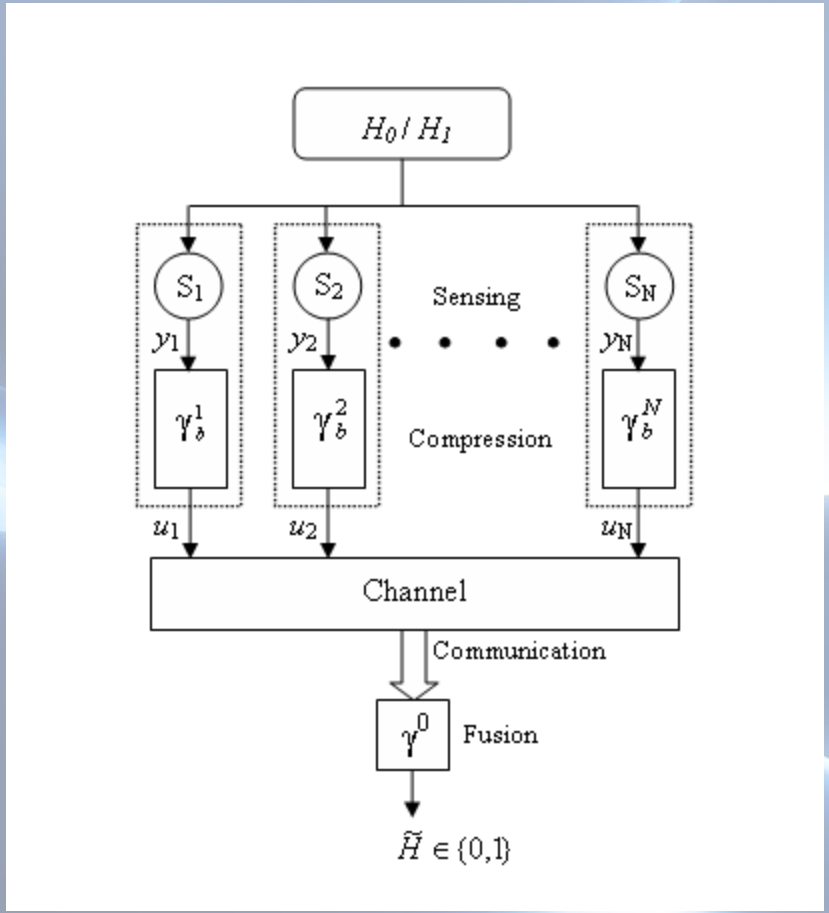
Research Challenges Subset

- **Identifying relevant information**
- **Information fusion**
- **Determining optimal control strategies**
- **Accounting for the communication links (fading/interference/network delays/ dropped packets)**
- **Operational lifetime of electronic components, i.e., energy considerations**
- **Resiliency to attacks**

Information Procesing (1/4)

- **Design of local sensor and global fusion rules**
- **Effect of decision feedback at the fusion center as well as local sensor**
- **Design of fusion receivers assuming a DS-CDMA based communication link**
- **Comparison of distance metrics for power allocation to local sensors**
- **Sensor deployment algorithm based on optimal control**

Distributed Detection



Information Processing (2/4)

Sponsor - US Marines System Command

Inputs:
- **Required detection probabilities**
- **Sensor parameters**
- **Terrain info**

Outputs:
Optimal Sensor locations

Control theory framework: A unique approach that has never been employed in sensor deployment problems prior to this effort

Information Processing (3/4)

-A low complexity algorithm is also proposed. Gives similar results to optimal method.

-Number of sensors used is 10% - 30% less than state of the art algorithms.

-Control False alarm by accounting for sensor collaboration

Information Processing (4/4)

When and what form of collaboration among sensors is effective from a performance as well as energy efficiency standpoint?

Sponsor – NSF EPSCOR, K-State Targeted Excellence Program

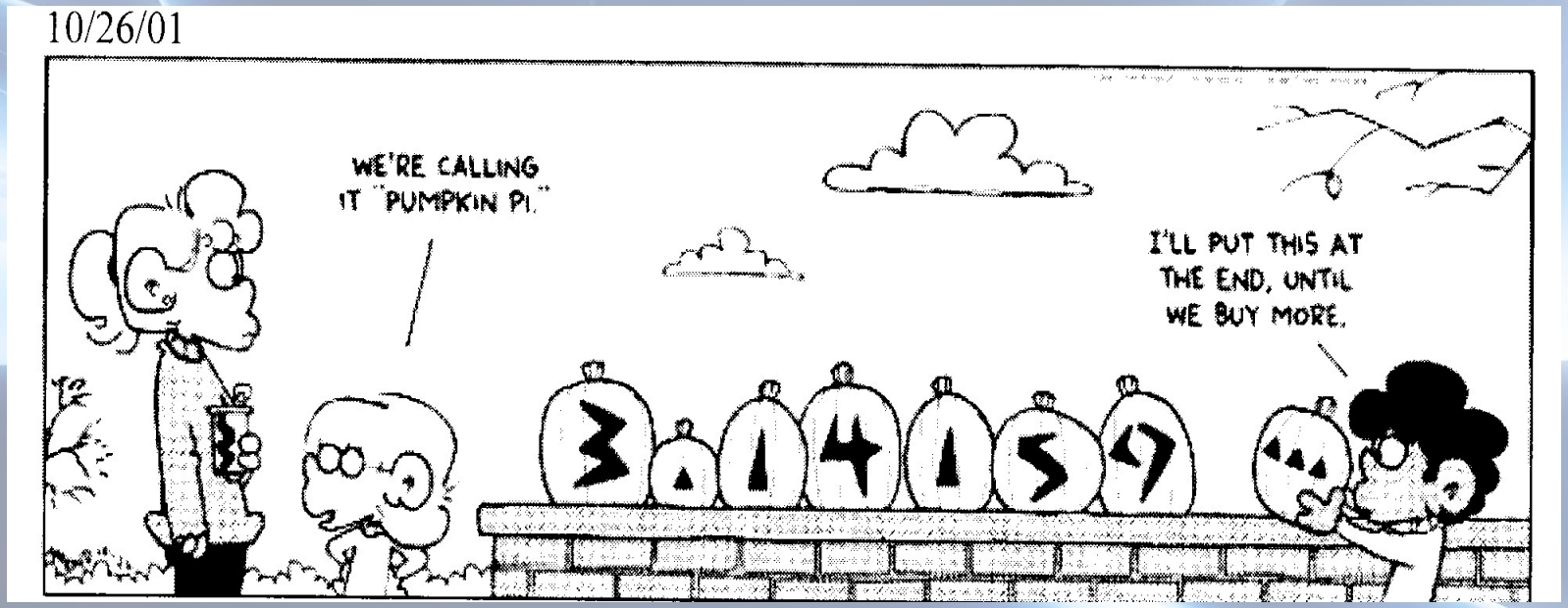
Distributed Estimation and Optimization

- **Distributed Online Filtering techniques for target tracking and localization – Kalman Filters, Particle Filters.**
- **What factors determine optimal sensor strategies and actions?**
  - **Error due to imperfect target state estimation**
  - **Erroneous communication over noisy fading channels**
  - **Effect of latency in distributed estimation**
  - **Residual battery power**
  - **Effect of being a popular sensor on network lifetime (fairness in load sharing)**

Concluding Thoughts

- Technology space is rich with possibilities
- Gap between research and implementation is wide – Military can close this gap
- Gives you the tools to run your (full spectrum) spread offense!
- Need to simultaneously develop our defense strategy – Pressure the other Quarterback with a team of Cyber warfighters
- **Training in the fields of Electronics, Wireless Communication, Information Processing is now a requirement for the Cyberspace domain!**

Thank You!



Courtesy: Foxtrot comics – www.foxtrot.com