Information Theory for Mobile Ad-Hoc Networks (ITMANET): ***The FLoWS Project***

FLoWS Update

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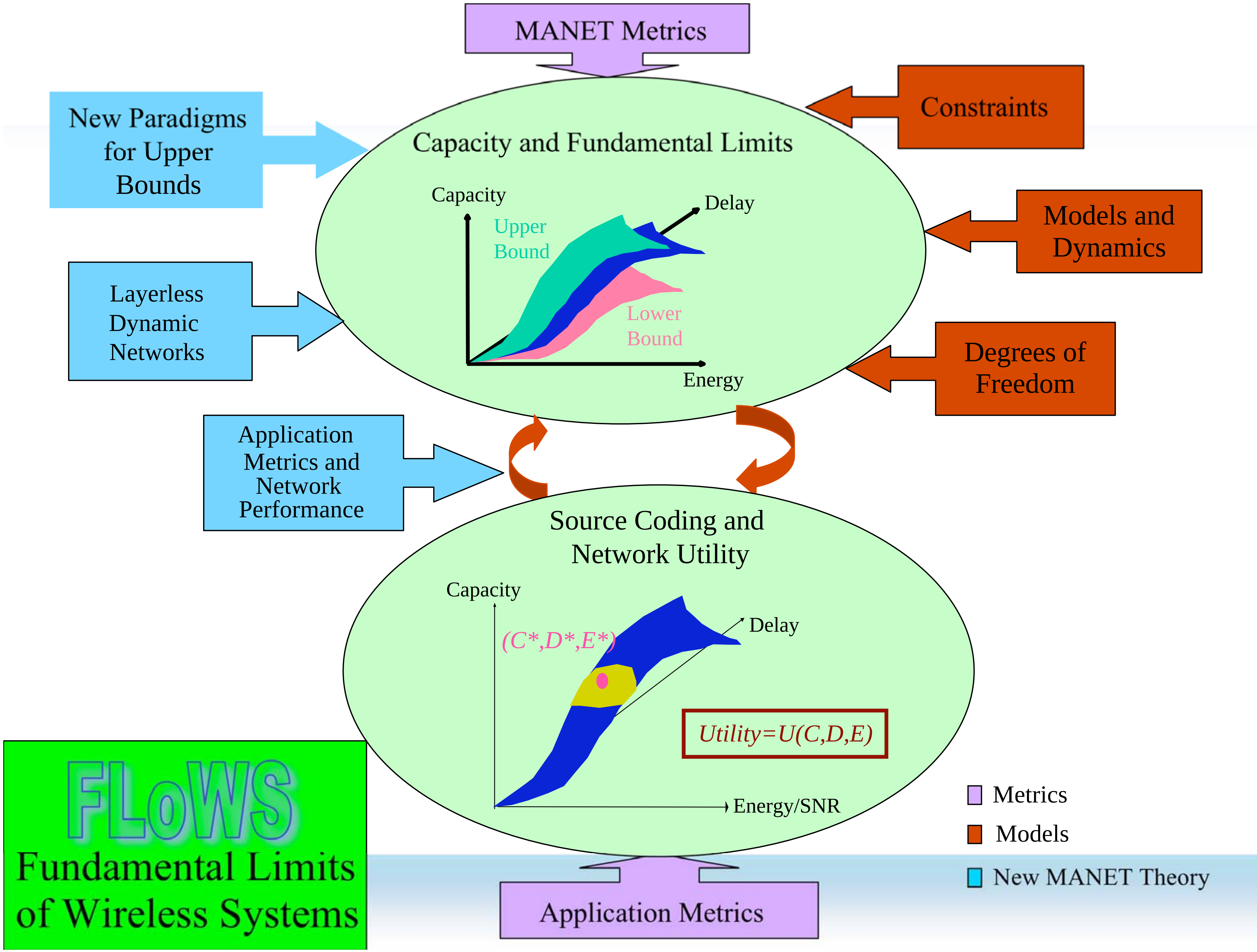
FLoWS Program Objectives

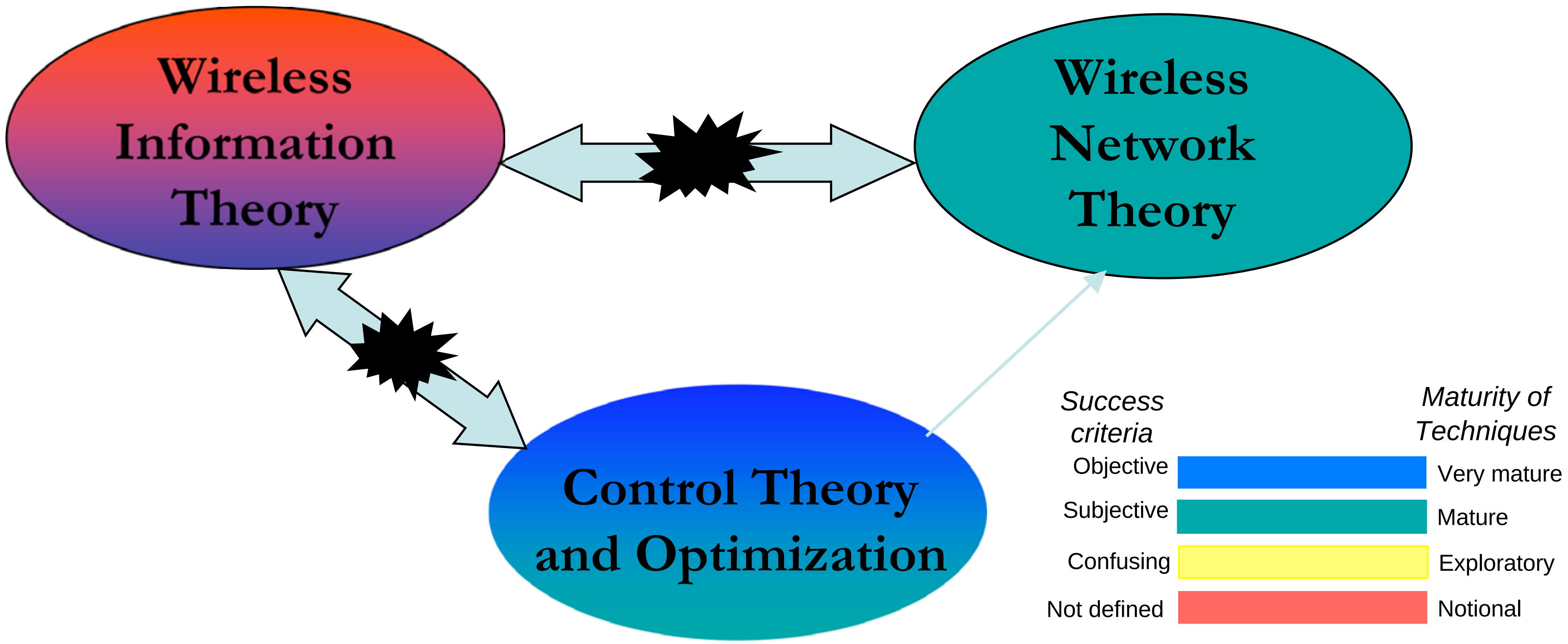
- Develop tractable and insightful metrics and models for MANET information theory.
- Define fundamental performance limits for MANETs in terms of desired objective metrics.
- Obtain upper and lower performance bounds for these metrics for a given set of MANET models.
- Define the negotiation between the application and network for resource allocation and performance optimization of our given metrics
- Bound the cost of using our set of metrics as the interface between the network and applications.


MANET Metrics
New Paradigms for Upper Bounds
Constraints
Capacity and Fundamental Limits
Capacity
Delay
Upper Bound
Lower Bound
Energy
Models and Dynamics
Layerless Dynamic Networks
Degrees of Freedom
Application Metrics and Network Performance
Source Coding and Network Utility
Capacity
(C*,D*,E*)
Delay
Utility=U(C,D,E)
Energy/SNR
FLoWS
Fundamental Limits of Wireless Systems
Metrics
Models
New MANET Theory
Application Metrics

Thrust Objectives and Scope

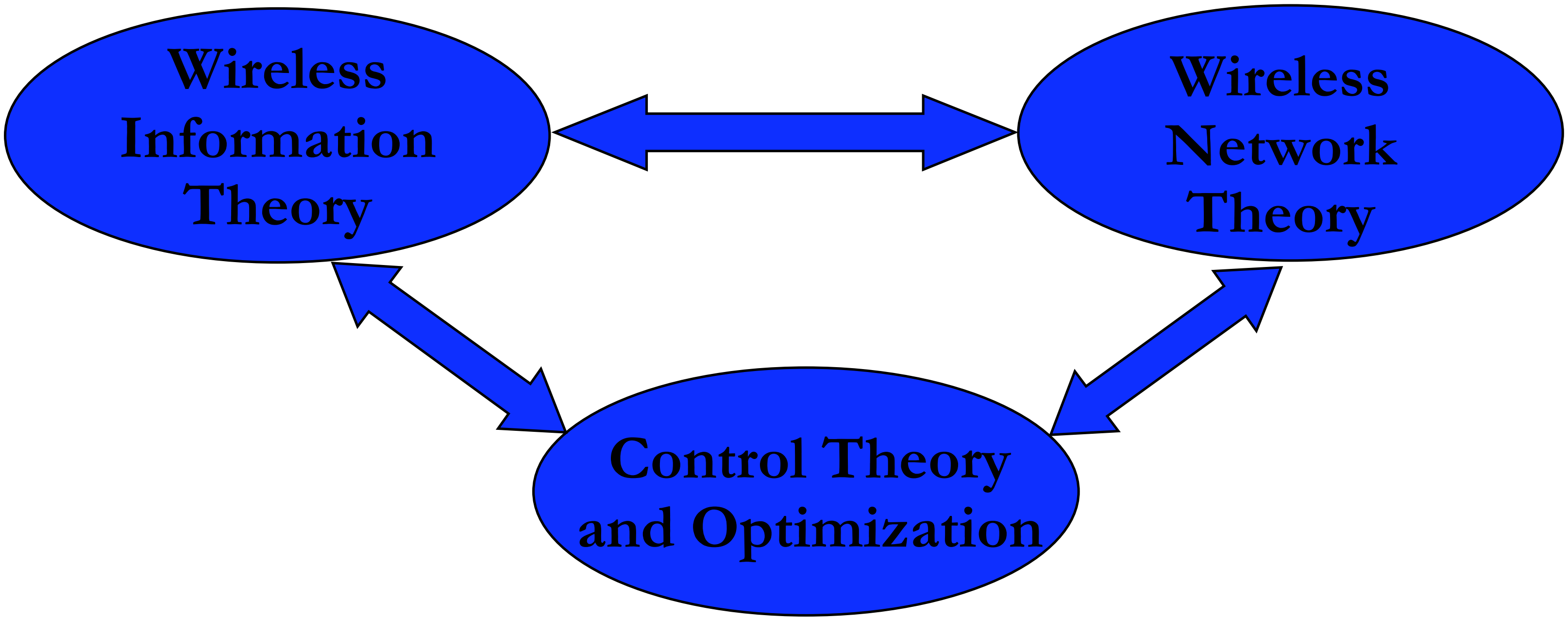
- **Models and Metrics** (Leads:Effros and Goldsmith):
  - ***Objective:*** Develop a set of metrics for dynamic networks that capture requirements of current and future applications
  - ***Scope:*** Develop a set of models for MANETs that are tractable yet lead to general design and performance insights
- **New Paradigms for Upper Bounds** (Leads:Koetter and Medard)
  - ***Objective:*** Obtain bounds on a diversity of objectively-defined metrics for complex interconnected systems.
  - ***Scope:*** A comprehensive theory for upper bounding the performance limits of MANETs
- **Layerless Dynamic Networks** (Lead:Zheng)
  - ***Objective:*** Design for networks as a single dynamic probabilistic mapping, without pre-assigned layered structure
  - ***Scope:*** Remove layering and statics from MANET information theory.
- **Application Metrics and Network Performance** (Lead:Ozdaglar)
  - ***Objective***: Provide an interface between application metrics and network performance
  - ***Scope:*** Develop a generalized theory of generlaized rate distortion, separation, and network optimization for MANETs

State-of-the-art Today



- Small isolated successes on narrowly-defined information theory of wireless networks.
- There is a large body of wireless (and wired) network theory that is ad-hoc, lacks a basis in fundamentals, and lacks an objective success criteria.
- Control theory and optimization very mature, with well-defined techniques and metrics.
- No cross-disciplinary ideas or synergies spanning these fields, except recent research that applies optimization and control techniques to existing wireless network designs.

Community Challenge: Consummate Union



- Develop a unified information theory of MANETs by:
  - Expanding the definition of information theory to encompass the nature and constraints inherent to wireless networks
  - Exploiting the powerful tools of control and optimization into this new theory
  - Obtaining fundamental capacity results and bounds under this broader definition
  - Using the new capacity theory and its associated insights to obtain fundamental breakthroughs in the theory of wireless network design.
  - Developing a generalized theory of rate distortion and network utilization to optimize the interface between networks and applications

Progress since January

- A wealth of results developing new paradigms and new synergies within and between our thrust areas
- New and ongoing collaborations among PIs, including student/postdoc exchanges
- Website online; design updated
  - Overview of the project as well as each thrust area
  - Summary of key program accomplishments to date, including the addressed challenge, potential impact, and key results
  - Presentations and posters from the January meeting
  - Publications
- Two PI Meetings
  - Advisory Board Meeting w/ Chan and Gallager (April 1, MIT)
  - Research Meeting (June 28, ISIT, Nice)
- ISIT Student Paper Award (Ng, Gunduz, et. al.)

Advisory Board Meeting Takeaways: General

- Want our research to provide challenges and solutions to the people that invent and build things.

- Fundamental research will have much greater impact on MANET design and performance than incremental research.

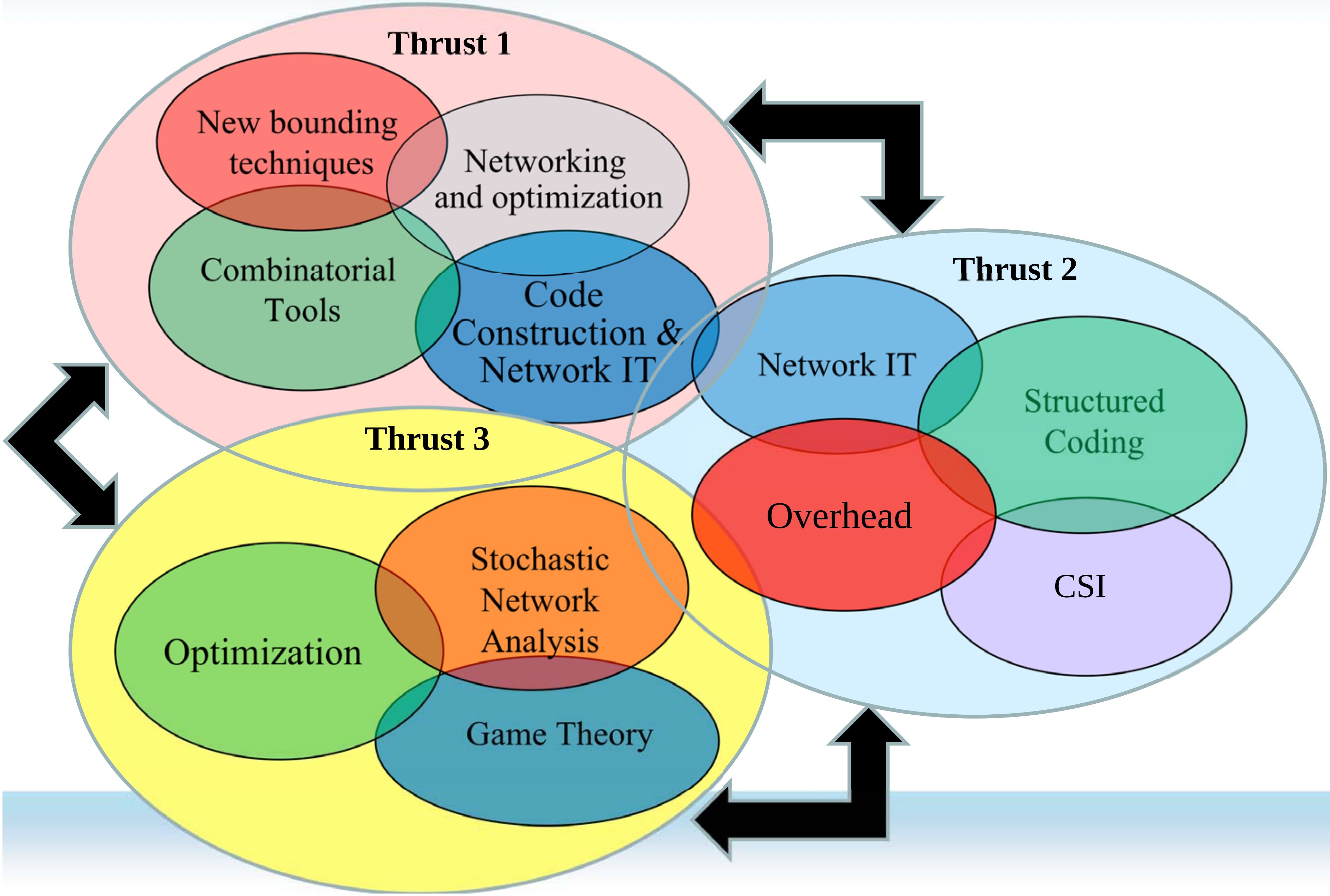
- Need to develop "Nuggets" about fundamental research in FLoWS and find a good way to desseminate them

Specific Areas of Importance (meeting notes)

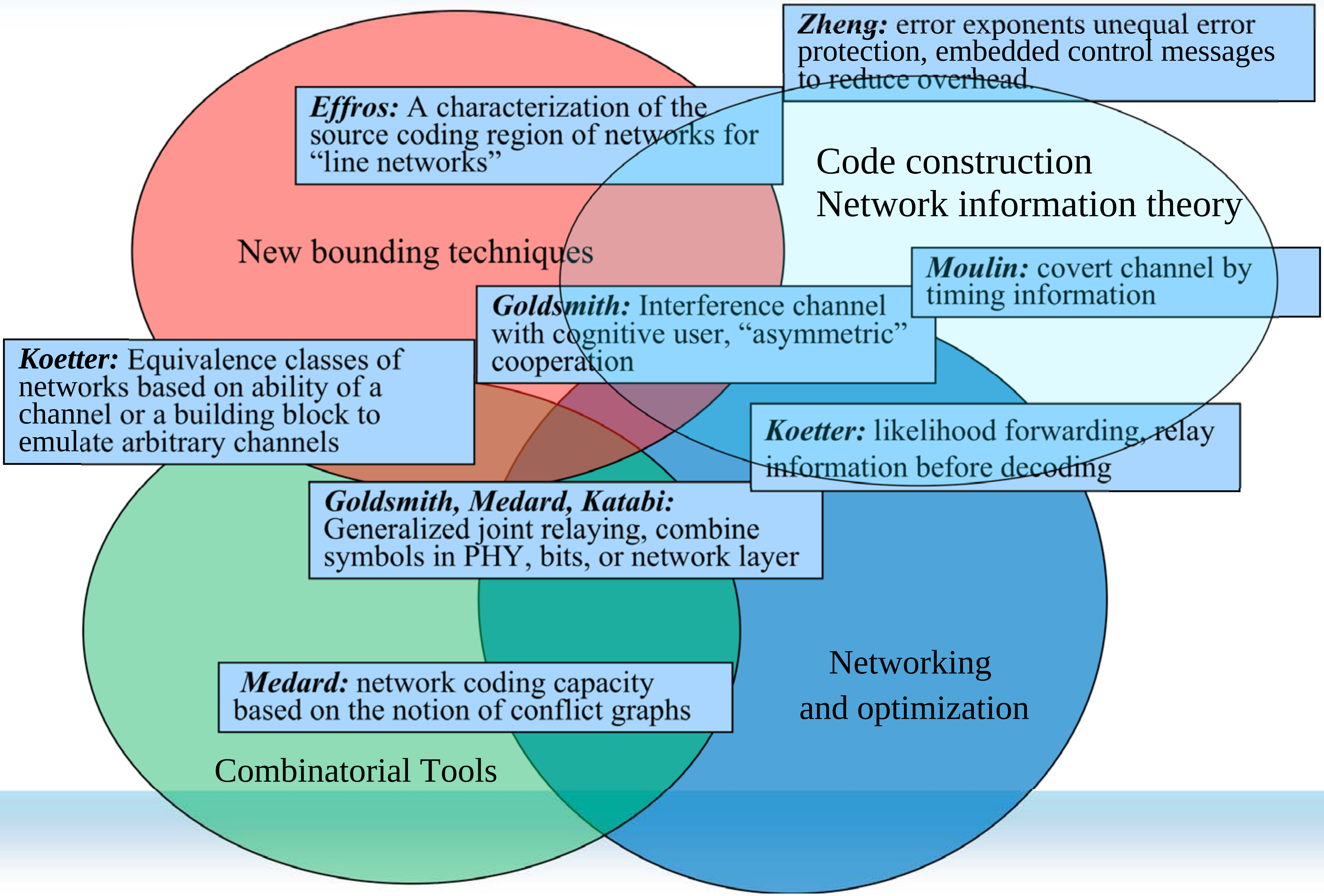
- Reliability: How and when to ensure a packet gets through (Goldsmith, Zheng, Coleman)
- Encoding/decoding: code size, a which node to decode, delay impact (Koetter, Medard, Effros, Goldsmith)
- Dynamics: impact of dynamics in networks. (distributed) algorithm convergence, overhead, game theory, imperfect CSI (Meyn, Ozdaglar, Shah, Boyd, Johari)

  Delay: Queuing fundamental to network design and is a big part of delay (added this to subtask 3, Shah)
- Priorities in Networks: Handle with kid gloves, Apps must chose where to operate (Ozdaglar, Shah, Johari)
- Control: Should not distort the real network problem to fit the existing optimization and control tools (All of thrust 3)
- Asymptotics: Try to see what can work asymptotically, what should go to infinity?

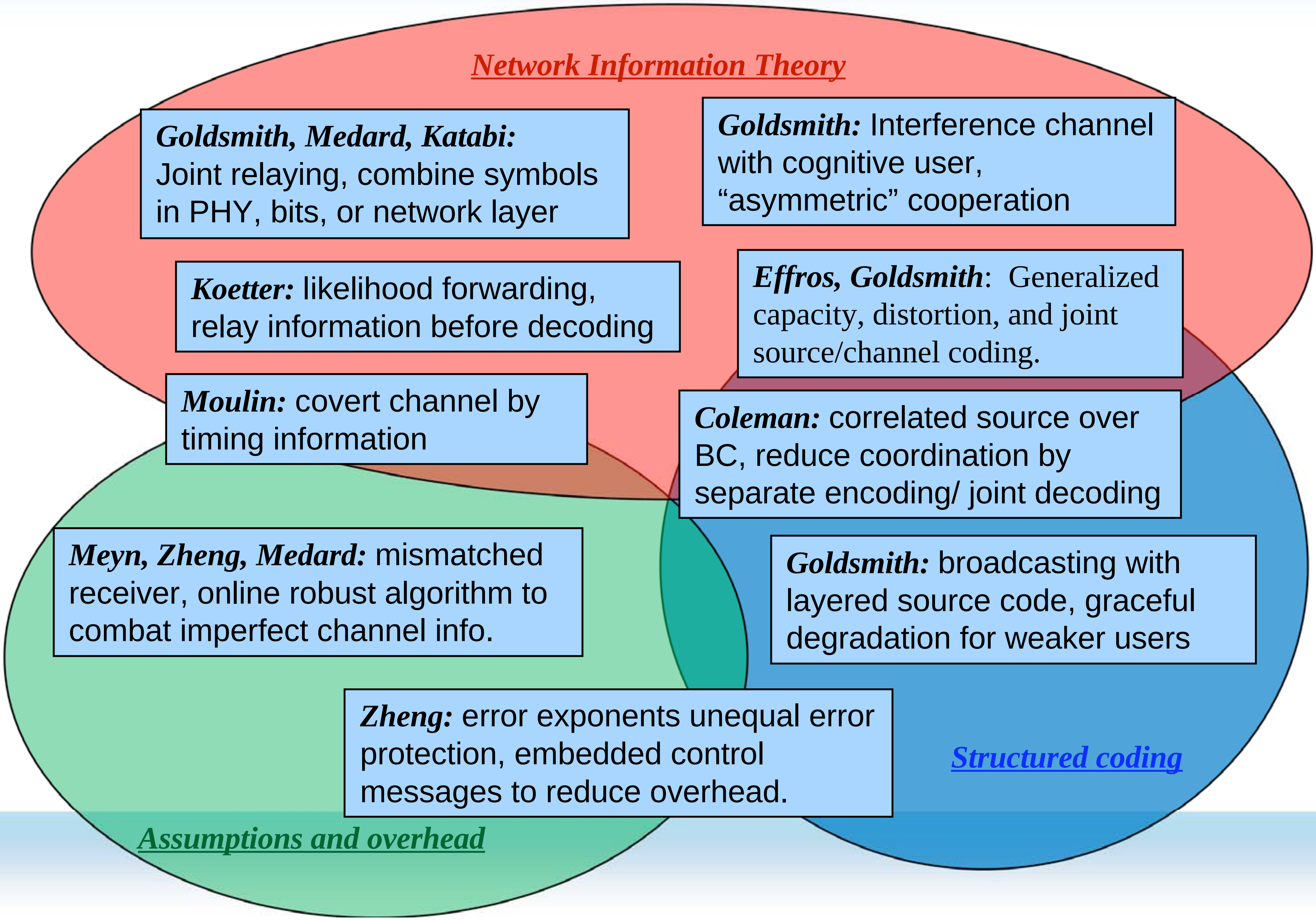
Thrust Synergies and New Intellectual Tools



Thrust 1 Synergies and Results



Thrust 2 Synergies and Results



Thrust 3 Synergies and Results

Optimization Theory
Distributed efficient algorithms for resource allocation

Boyd: Efficient second order methods for flow control

Shah: Throughput analysis of flow-level models with heterogeneous users

Ozdaglar: Distributed asynchronous optimization algorithms for general metrics and time-varying connectivity

Shah: Low complexity throughput and delay efficient scheduling

Goldsmith, Johari: Game-theoretic model for cognitive radio design in the presence of incomplete channel information

Meyn: Generalized Max-Weight to tradeoff information and performance

Johari: Topology formation model with application goals such as connectivity and cost of routing and link maintenance

Ozdaglar, Shah: Distributed scheduling and flow control to balance user and network performance

Stochastic Network Analysis
Flow-based models and queuing dynamics

Game Theory
New resource allocation paradigm that focuses on hetereogeneity and competition

Progress Criteria: Phase 1

- Develop tractable and insightful metrics and models that expand the definition of information theory to encompass the degrees of freedom, constraints, and dynamics inherent to wireless networks
- Develop new upper bounding techniques for MANET capacity and other performance metrics and evaluate these bounds for small to medium sized networks under relatively simple assumptions.
- Develop new achievability results for key performance metrics by optimizing dynamic node cooperation and resource allocation over available degrees of freedom.
- Use rate distortion theory and network utilization to optimize the interface between networks and applications.
- Use new theory along all three thrusts to characterize trade-offs between delay, energy and capacity, and possibly other metrics.
- Demonstrate significant performance gains in key performance metrics based on our developed theory in each thrust area.
- Use the new MANET information theory and its associated insights to obtain breakthroughs in wireless network design.