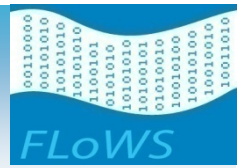


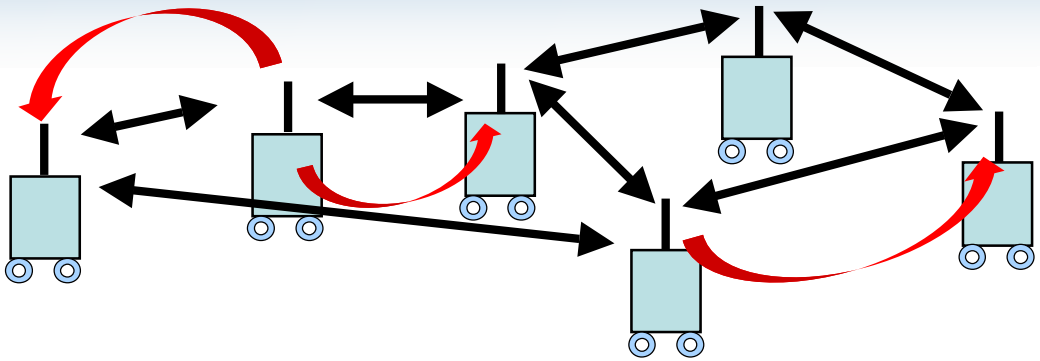
Information Theory for Mobile Ad-Hoc Networks (ITMANET):
The FLoWS Project

FLoWS Summary: Past, Present, and Future

Andrea Goldsmith

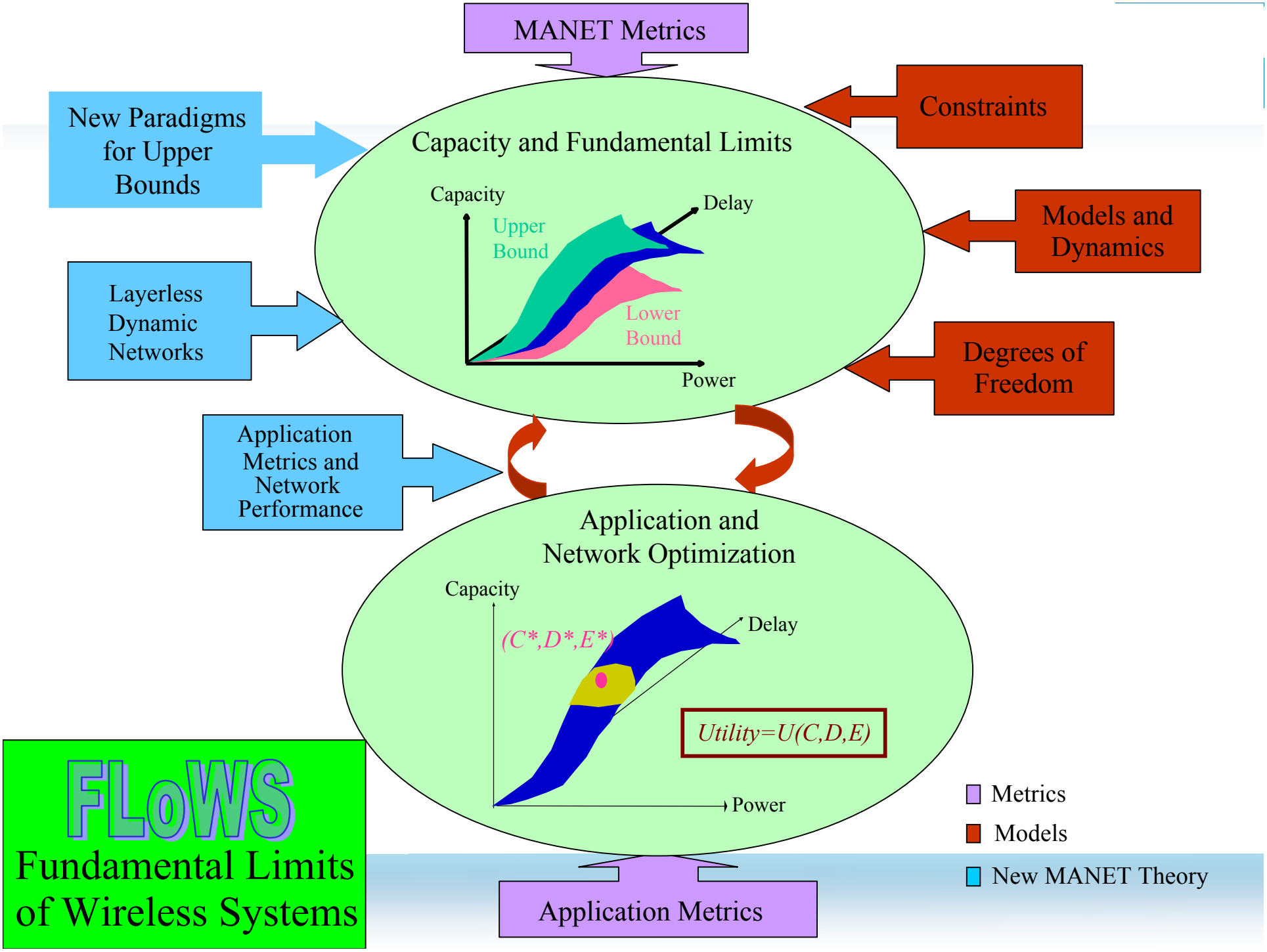
ITMANET PI Meeting
Jan 26, 2011

FLoWS Challenge

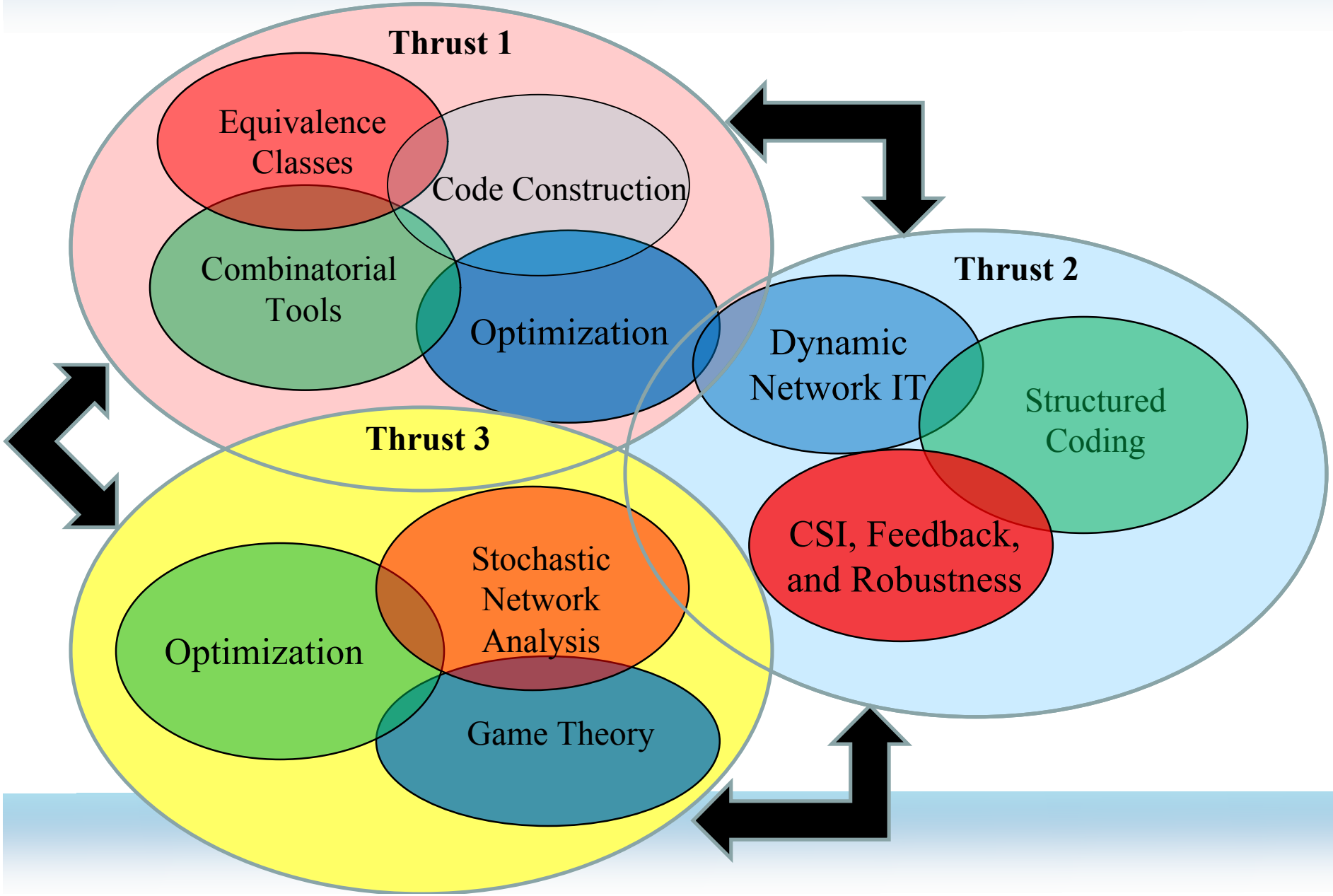


- Much progress in finding the Shannon capacity limits of wireless single and multiuser channels
- Limited understanding about these capacity limits for wireless networks, even with simple models
- System assumptions such as constrained energy and delay require new capacity definitions
- Define and determine “fundamental limits” of MANETs?

Develop and exploit a more powerful information theory for mobile wireless networks

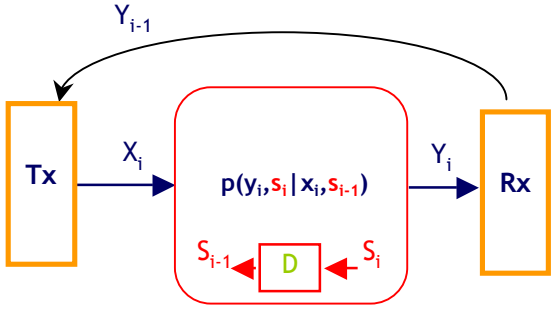

MANET Metrics
Constraints
New Paradigms for Upper Bounds
Capacity and Fundamental Limits
Capacity
Delay
Upper Bound
Lower Bound
Power
Models and Dynamics
Layerless Dynamic Networks
Degrees of Freedom
Application Metrics and Network Performance
Application and Network Optimization
Capacity
(C*,D*,E*)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

Thrust Synergies and New Intellectual Tools

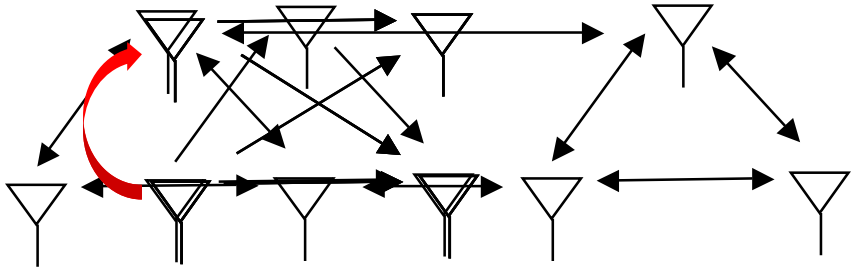


Open Questions circa 2006

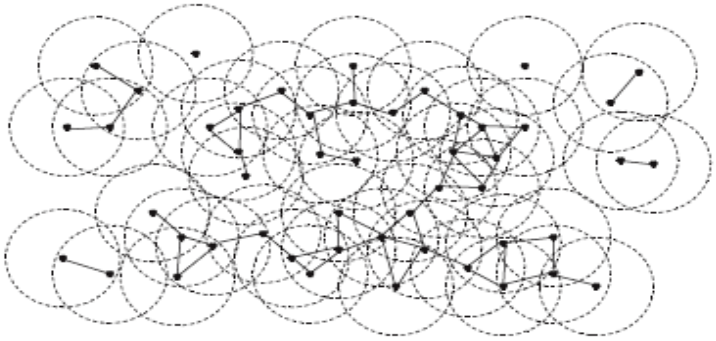
- Capacity of time-varying links (with/without feedback)



- Capacity of basic network building blocks

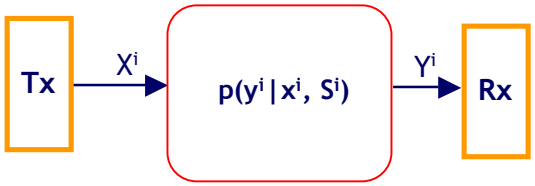


- Capacity of large dynamic networks



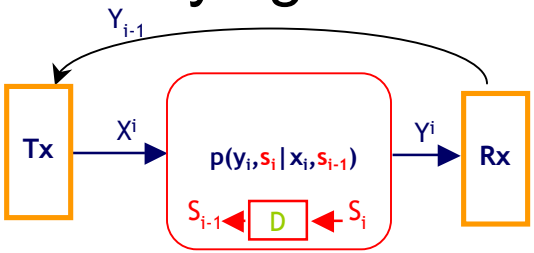
Progress on these questions

- Capacity of time-varying links without feedback



  - Outage and expected capacity
  - Channel equivalence
  - Unequal error protection

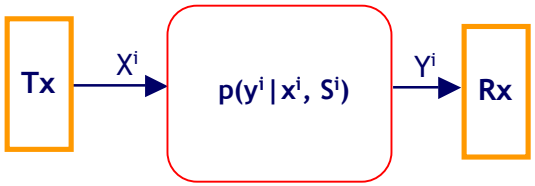
- Capacity of time-varying links with feedback



  - Capacity of Markov channels under feedback
  - Directed information
  - Impact of rate-limited feedback on error exponents
  - Control principle and tilted matching for feedback channels
  - Joint source/channel coding with limited feedback

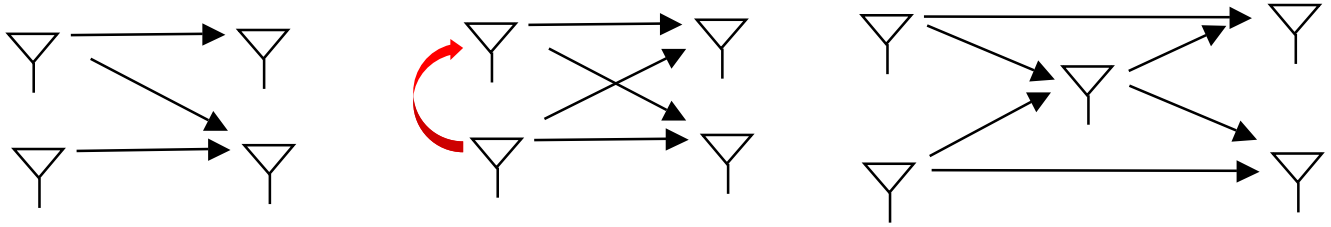
Progress on these questions

- Delay Constraints



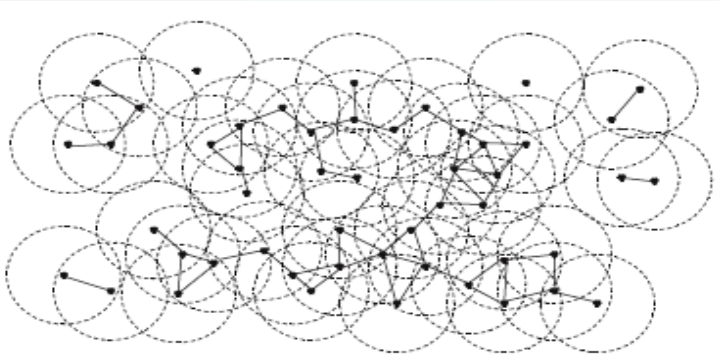
  - Instantaneous efficiency
  - Multiplexing-diversity-delay tradeoffs in MIMO
  - Finite-blocklength codes
  - Delay-energy tradeoffs

- Capacity of basic network building blocks



  - Z Channel
  - Interference channel
  - Cognitive radio channel
  - Interference channel with a relay

Capacity of dynamic networks



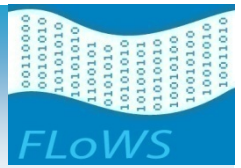
- Structured Coding
  - Network equivalence
  - Scaling laws for arbitrary node placement and demand
  - Noisy network coding; analog network coding
  - Multicast capacity
  - Interference decoding and forwarding
  - Coordinated capacity

- Optimization and Game Theory
  - Dynamic/multiperiod network utility maximization
  - Distributed optimization and learning
  - Generalized Max-Weight policies
  - Game-theoretic approaches and mean-field equilibrium

Key New Theory and Insights

- Thrust 0
  - New definitions of reliable communications in the face of uncertainty
  - Performance over finite time windows
- Thrust 1
  - Network Equivalence
  - Network Coding in Noise/Loss
  - Multiterminal Strong Converses
- Thrust 2
  - Layered and structured codes
  - Control/capacity connections for time-varying channels with noisy and/or rate-constrained feedback
  - Generalized capacity and separation
- Thrust 3
  - Stochastic Multi-period Network Utility Maximization
  - Relaxation and distributed techniques for network optimization
  - Mean Field Equilibrium for Stochastic games
  - Learning in dynamic environments
- Interthrust
  - Coordination via Communication
  - Relaying, cooperation and cognition
  - Network coding
  - Capacity regions for more than 3 users

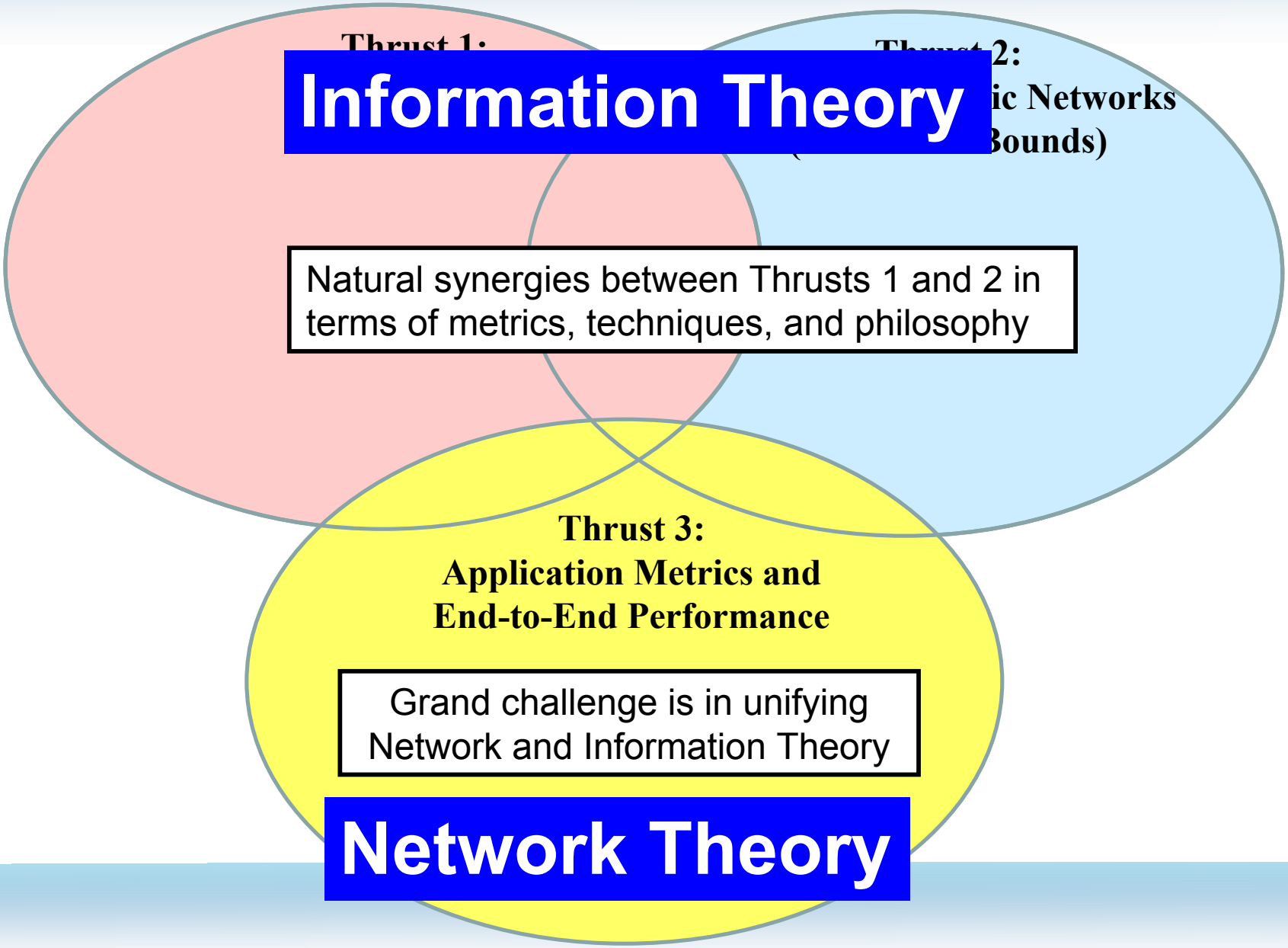
Wish List for New Theory and Insights



- Definition(s) for “fundamental performance limits” in MANETs
- Optimal use of noisy/rate constrained feedback
- Network capacity under delay constraints
- (Near)-optimal codes for large networks
- Paradigms for MANET protocol layering
- Network equivalence for large networks
- All joint distributions achievable over networks
- Consummated union between information and network theory in MANETs

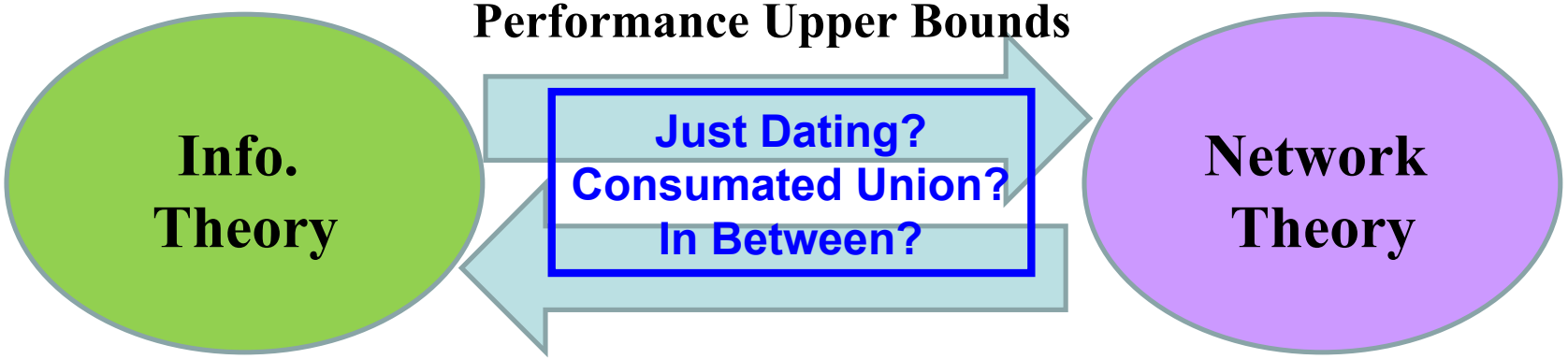
To be revised in team meeting

Grand Challenges towards a Unified Theory



Information Theory meets Network Theory

Abstractions
Coding Strategies
Insights (from Achievable Schemes)
Performance Upper Bounds



Insights
Learning/CSI/"Network Management"
Distributed Algorithms
Performance Limits for Large Networks
Robustness
Scaling Laws
Cross-Layer Design

Common performance metrics required for unification

Future

- How to attack and update our wish list
- How to inspire other researchers to pursue these goals
- How to disseminate program results and maximize their impact
- Focus of a potential follow-up program
- How to transfer the results of ITMANET into practice
  - Commercial, military, or both

PI meeting presentations

- Equivalence Beyond Random Channels: Effros
- Wireless Network Coding: Medard
- Dynamical Systems & Reliable Communication: Coleman
- Distributed Optimization via the Alternating Direction Method of Multipliers: Boyd
- Martingale Lattices: Cover
- Finite-Blocklength Universal Coding for Multiple-Access Channels: Moulin
- On Instantaneous Efficiency of Dynamic Communications: Zheng
- Distributed Optimization with State-Dependent Communication: Ozdaglar
- Positive Recurrent Medium Access: Shah
- Mean Field Equilibrium in Games: Johari

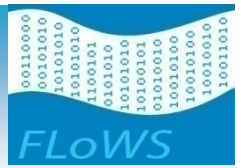
Posters

- Thrusts 1 & 2:
  - A comparative taxanomy of wireless networks in the wideband regime: Fawaz, Thakur, Medard
  - A converse for the wideband relay channel: Fawaz, Medard
  - Instantaneous Efficiency of Communication: Zheng
  - Optimal relay location and power allocation for low SNR broadcast relay channels: Thakur, Fawaz, Medard
  - Reduced-Dimension Multi-User Detection: Y. Xie, Y. Eldar, A. Goldsmith
  - Shannon meets Nyquist: Capacity limits of sampled analog channels: Chen, Goldsmith, Eldar
  - Separation of source-network coding and channel coding in wireline networks: Jalali, Effros
  - Network equivalence in the presence of Adversary: Effros

Posters

- Thrust 3
  - Mean Field Equilibria of Dynamic Auction with learning: K. Iyer, R. Johari, and M. Sundararajan
  - Metrics and control algorithms for media streaming in heterogeneous networks: Medard, Ozdaglar
  - Optimal control of ARQ interference networks Levorato, Firouzabadi, Goldsmith
  - Positive Recurrent Medium Access: Shah
  - Scheduling for Small Delay in Wireless Downlink Networks: Bodas

Summary



- Powerful new theory has been developed that goes beyond traditional Information Theory and Networking.

- Significant impact of FLoWS research on the broader research community (IT, communications, networking, and control/optimization).
  - Has yet to bring these groups together in a significant way outside the ITMANET team members

- Remainder of program should focus on making progress on our research wish list and identifying how to maximize the impact of the ITMANET program on future research.