Harnessing Mobility in Adhoc Networks

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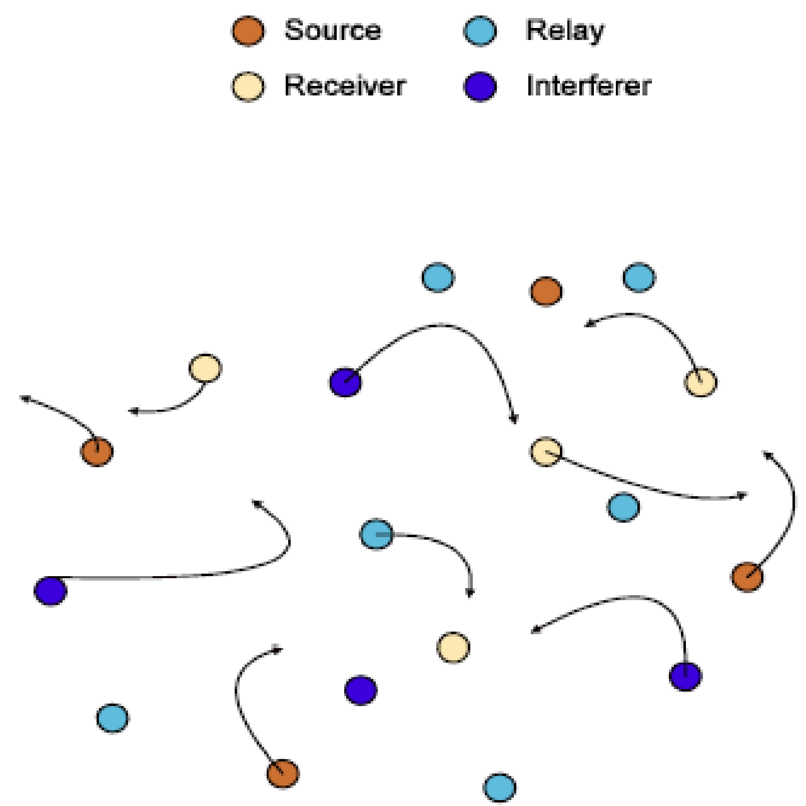
Introduction

- Adhoc Networks
  - Dynamically self-interlinking transceivers
  - Nodes cognizant of their neighbors
  - Simultaneous end-end data flows through localized cooperation
  - No central controlling agent

- Basis for Active Node Mobility
  - Improvement of node awareness
  - Nodes with autonomy over their spatial location
  - Nodes move around to conserve energy or improve data flow rate

Motivation

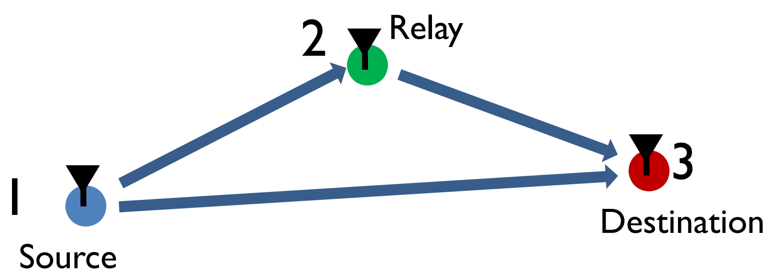
- Is there an optimal location that each node should move to, subject to localized mobility restrictions?
- What happens when nodes have conflicting interests?



An example MANET with node mobility

Single Relay Channel (SRC)

- A simple 3-terminal adhoc network block
- Incorporates crucial elements such as cooperation, interference between nodes



- General Capacity region of the SRC is unknown
- Several achievable rate schemes have been formulated
  - Amplify and Forward
  - Decode and Forward
  - Compress and Forward

Upper bounds for the SRC

- Cut-Set Bound
  - Upper bound on capacity for multi-terminal systems
  - Extension of the celebrated Ford-Fulkerson theorem to networks
  - The cut-set bound is given by

$$C \leq \sup_{P(X_1 X_2 \ldots. X_n)} \min(I(X_S; Y_{S^C} \mid X_{S^C}))$$

over all possible subsets S of nodes {1,2,3,…n} containing the source and not the destination.

X and *Y* are the transmit and receive symbols.

  - When applied to the SRC,

$$C \leq \sup_{P(X_1 X_2)} \min(I(X_1; Y_2, Y_3 \mid X_2), I(X_1, X_2; Y_3))$$

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Achievable Rate Schemes

- Decode and Forward (DF)
  - Relay node decodes all the source information
  - Cooperates with source to retransmit this to the receiver
  - Rate region given by

$$R \le \sup_{P(X_1 X_2)} \min(I(X_1;Y_2 \mid X_2), I(X_1, X_2;Y_3))$$

- Compress and Forward (CF)
  - Relay quantizes its received signal and forwards to the destination

$$R = I(X_1;\overline{Y_2}, Y_3 \mid X_2)$$

$$I(\overline{Y_2};Y_2 \mid X_2, Y_3) \le I(X_2, Y_3)$$

SRC with 1-D relay mobility

- Gaussian Channel model is employed for each link

$$Y_2 = \frac{X_1}{d} + Z_2; \qquad Y_3 = X_1 + \frac{X_2}{1-d} + Z_3$$

- Source and the Relay have transmit power constraints P_1 and P_2 respectively
- Relay is at distance d from the source on the S-D line
- Quadratic path loss is assumed.
- Noises Z_2 and Z_3 are uncorrelated unit variance
- The cut-set bound is evaluated as

$$C \le \sup_{0\le\rho\le 1} \min\left(\frac{1}{2}\log\left(1+(1-\rho^2)P_1\left(1+\frac{1}{d^2}\right)\right), \frac{1}{2}\log\left(1+P_1+\frac{P_2}{(1-d)^2}+2\rho\frac{\sqrt{P_1P_2}}{|1-d|}\right)\right)$$

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SRC with 1-D relay mobility (contd..)

- DF and CF have rates given by

$$R_{DF} \leq \sup_{0 \leq \rho \leq 1} \min\left(\frac{1}{2}\log\left(1+(1-\rho^2)\left(\frac{P_1}{d^2}\right)\right), \frac{1}{2}\log\left(1+P_1+\frac{P_2}{(1-d)^2}+2\rho\frac{\sqrt{P_1P_2}}{|1-d|}\right)\right)$$

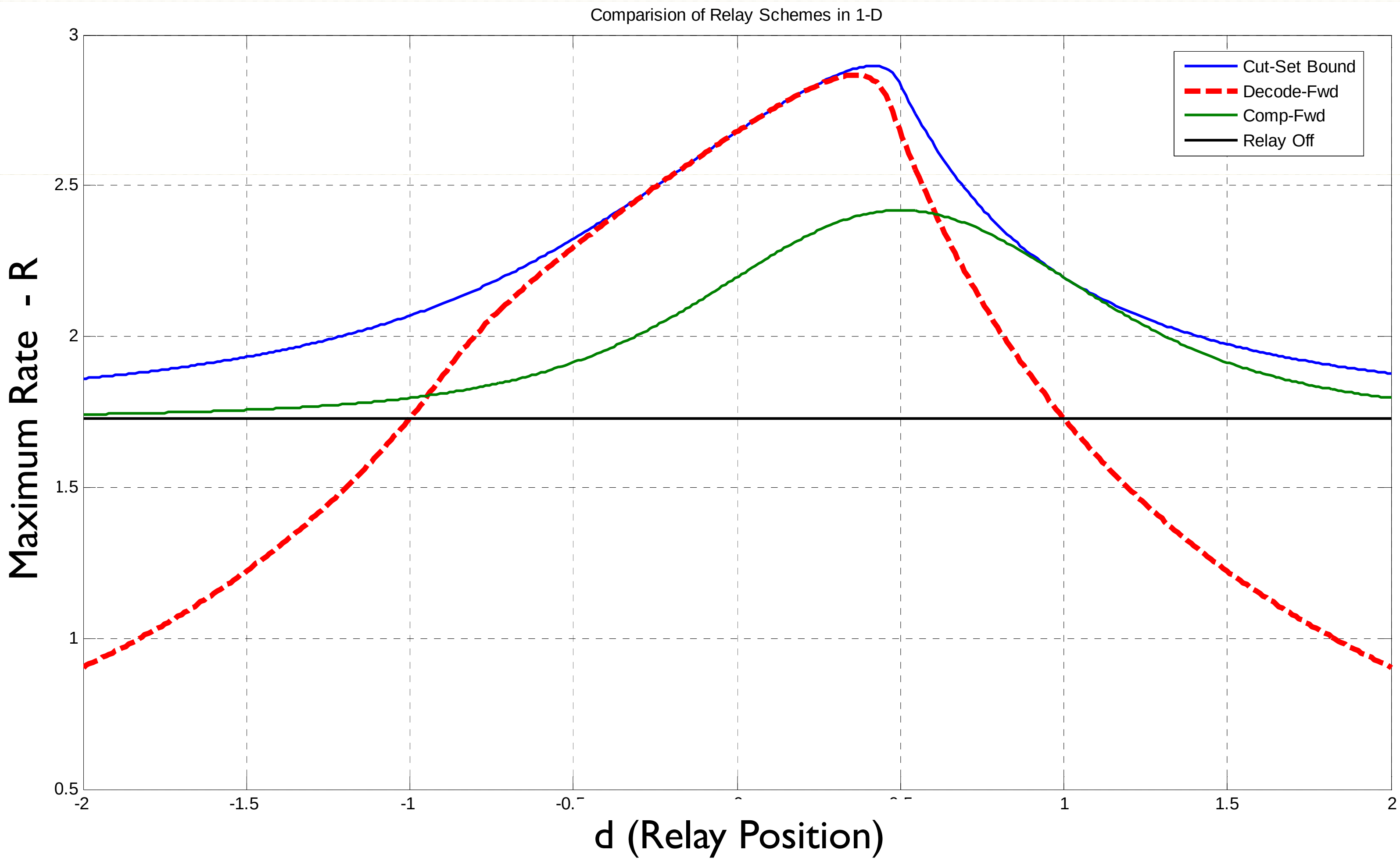
where ρ is the cooperation between X_1 and X_2

$$R_{CF} = \frac{1}{2}\log\left(1+P_1+\frac{P_1}{d^2(1+\overline{N_2})}\right); \overline{N_2} \geq \frac{1+P_1(1+\frac{1}{d^2})}{\frac{P_2}{(1-d)^2}}$$

where $\overline{N_2}$ is the minimum distortion in Y_2 allowed by the channel between relay and destination

- Simulation plots give an intuition about the optimal location of the relay node

I-D Relay Mobility Simulation



- Relay is most effective around the midpoint of Source Destination
- Relays only within 2 units of source are suitable for cooperation
- DF is useful when relay is in source proximity while CF is better in destination proximity

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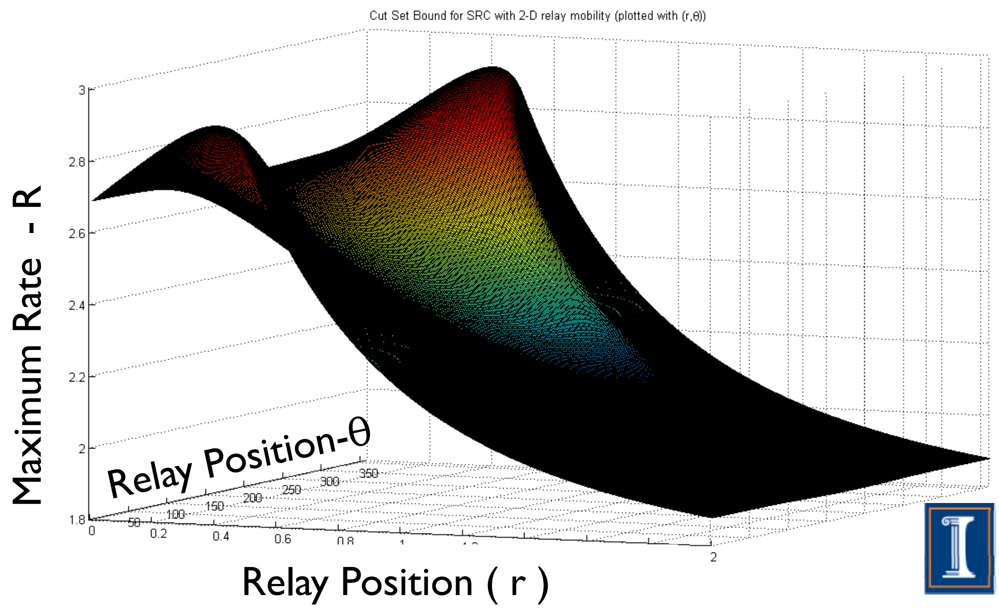
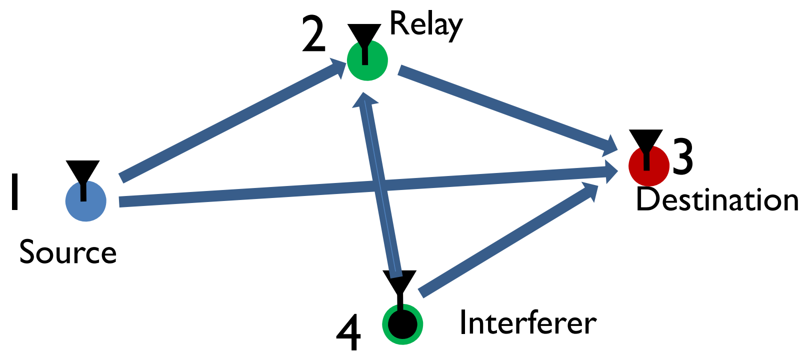
SRC with 2-D relay mobility

- Using the same framework for the rest of the system, the relay is allowed to be at an arbitrary (r, θ) in 2-D
- The rate regions are computed as in 1-D case
- The following observations are made
  - Relay is most effective on the line joining the S-D pair
  - So optimal relay location remains under unrestricted mobility
  - With restrictive mobility, appropriate relay location can be chosen from the plots
- Plot of cut-set bound in 2-D



SRC with Interferer

- We model external interference from a non-cooperative node in the system
- Power of the interferer's signal X_4 is limited to I
- The system model is as shown below



$$Y_2 = \frac{X_1}{d_{12}} + \frac{X_4}{d_{24}} + Z_2; \qquad Y_3 = X_1 + \frac{X_2}{d_{23}} + \frac{X_4}{d_{34}} + Z_3$$

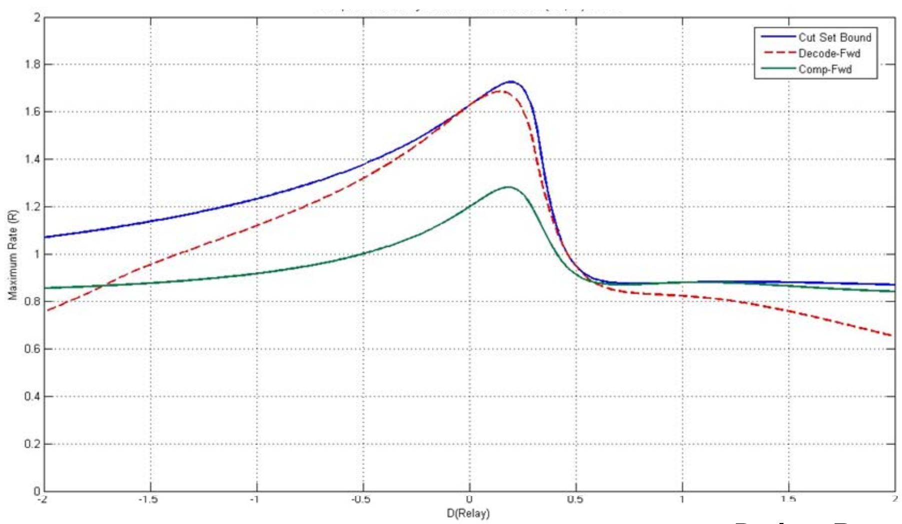
- Interferer location is held constant and performance metrics are examined while varying the relay location

Simulations for SRC with Interferer

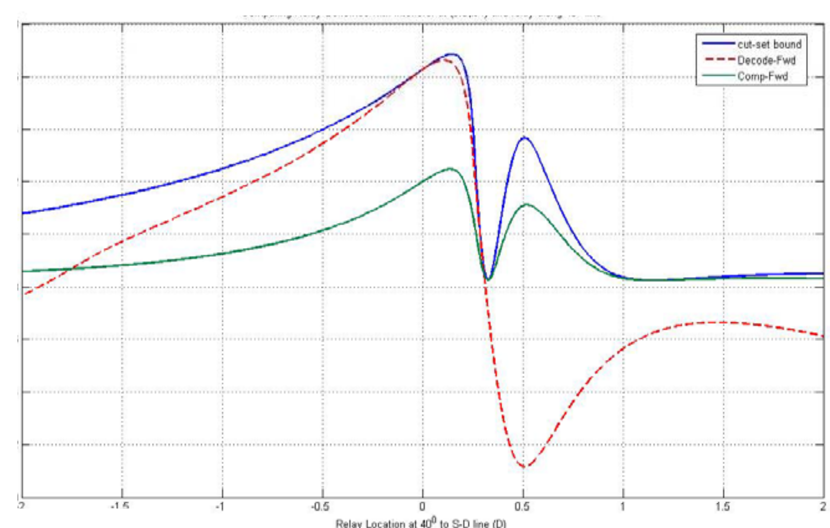
- The performance metrics are evaluated for relay locations in 2-D.
- S-D are held at unit distance and Interferer arbitrarily placed in the vicinity.
- The following plots show metrics along two different axis of relay mobility

Maximum Rate - R

Relay moved along S-D axis



Relay moved along an axis close to interferer



Relay Position (r)

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Observations for system with Interferer

- The second plot shows considerable gain in achievable rates along an axis close to the interferer
- Compress and Forward performs significantly better closer to the interferer
- Interference cooperation is possible due to correlated noise in Y_2 and Y_3
- The spatial region in which an active relay improves capacity expands in the presence of an interferer
- The optimal location for the relay becomes non-trivial and no-longer on the S-D axis.

Conclusion and Future Directions

- Node locations play an important role in determining system capacity
- Relay location becomes increasingly important in the presence of an added interference
- Mobility can be used to actively mitigate interference at the destination through CF scheme

- Future Directions
  - Look at impact of mobility in other Adhoc network blocks
  - Work could be extended for Multiple relay systems
  - More realistic channel models with fading need to be considered

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