Cooperating with Smartness
Using Heterogeneous Smart Antennas in Ad Hoc Networks

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Outline

- Introduction
- Node Co-operation in HSANs
- Adaptive Co-operation mechanism
- The MACH protocol
- Performance evaluation of MACH
- Conclusions
Introduction

- Smart antennas
  - Switched beam -> LOS
  - MIMO (adaptive array antenna) -> NLOS

- Motivation
  - Economic feasibility
  - Mesh networks (arbitrary)

- Retransmit diversity
Smart node

- In switched beam antennas, a pre-defined set of weights is used, each of which results in a beam pointing to a particular direction with a high SNR gain (LOS).
- For strong multipath scattering (NLOS) environments, it is the adaptive array antennas that are capable of adapting their weights and hence beam pattern to maximize the resulting SNR.
Node cooperation in HSANs

a) Node Cooperation

b) Node Cooperation in HSANs

Fig. 2. Cooperation Gain
Properties

Lemma 1: $G_{c,R} \geq G_{c,A}$

a) $P_{out}: p=30, f=1$

b) Gain: $p=20, K=2$

Fig. 3. Outage and Gain Results
Lemma 2: $G_{c,R}$ is a concave function in the (fractional) number of smart nodes in the network, $p_x \in (0, 1]$.

Fig. 4. Cooperation Gain Results
Adaptive Co-operation mechanism

- $C_{\text{ant}}$ : basic cooperation which favors antenna gain
- $C_{\text{coop}}$ : after experiencing a fading loss, switches to omni-directional mode to favor cooperation

\[ \text{Lemma 3: When } p_x \rightarrow 1, \]
\[
G_{C_{\text{ant}}} \geq G_{C_{\text{coop}}}, \quad f = 1 \\
G_{C_{\text{coop}}} \geq G_{C_{\text{ant}}}, \quad f = F
\]
**Mechanism $C_{adap}$**

- If there are multiple neighbors, the one with the largest link gain will take part in the cooperation.
- Transmitter reduces its rate to omni rate and starts exploiting the antenna gain for reliability from the second trial onwards.
- If the transmitter is a smart node:
  - Elements for rate switch to reliability
  - Switches to using three elements for reliability
  - omni-directional transmission
Proposition 1: If $q_o$ and $q_3$ are probabilities of finding a relay in the case of an omni transmission and a spatially sensitive transmission made with three elements respectively, then $\frac{1}{3} \leq \frac{q_3}{q_o} \leq 1$. [Proof in [9]]

c) Gain: $f=1$

d) Gain: $f=3$

Fig. 5. Performance of Different Strategies
The MACH protocol

- Weighted proportional fairness model
- Distributed persistence algorithm
  \[ a_i = \alpha w_i - \beta p_i a_i \]
- \( P_i \): loss probability of the flow \( i \)
- \( W_i \): the weight assigned to the flow (SNR gain)
- \( a_i \): persistence probability
- \( \alpha \): utility constant
- \( \beta \): penalty constant
 Protocol details

- Fading loss detection
  - Source append a short preamble to the DATA packet
  - For identifying fading loss
  - High reliability
  - Low rate
  - Small size (avoid overhead)
S

RTS

DATA

Smart/omni mode

D

Preamble decode ok

Data decode fail

Change strategy to reliability

R

help

OK

R'

help
I can be a relay

Drop the packet
Performance evaluation

Throughput

1000m * 1000 m  100 node
UDP protocol
100 seconds
10 times

a) LOS: Fraction (x, 4, 5, 30)

b) NLOS: Fraction (x, 6, 10, 30)
Throughput

**c) NLOS: SNR (20,6,x,30)**

**d) LOS: Load (40,4,15,x)**

Fig. 6. Throughput Results: (Fraction,Elements,T_SNR,Flows)
Fairness

c) LOS: Fraction (x,4,10,30)  
d) NLOS: Load (40,4,10,x)
Conclusions

- We considered the problem of ad-hoc networks with heterogeneous antenna technologies.
- The MACH protocol that incorporate the proposed cooperation mechanism makes the performance better.