Incentive Compatible Broadcast in Ad hoc Wireless Networks

Rama Suri Narayanam

Dept. of Computer Science and Automation
Indian Institute of Science

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Outline of the Talk

Quick Recap

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  - to weaken the implementation concept and look for an SCF which is *ex-post efficient*, *non-dictatorial*, and *Bayesian incentive compatible*

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  - **to weaken the implementation concept and look for an SCF which is ex-post efficient, non-dictatorial, and Bayesian incentive compatible**

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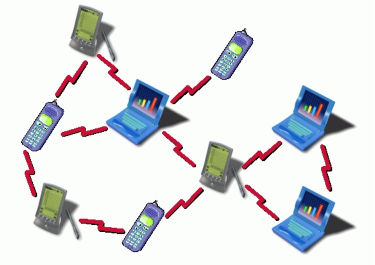
- No fixed infrastructure
- Each node is also router
- Applications of ad hoc networks:
  - Military Applications,
  - Wireless Sensor Networks,
  - Mesh Networks



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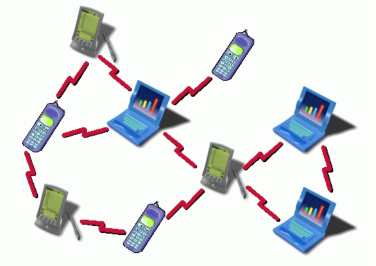

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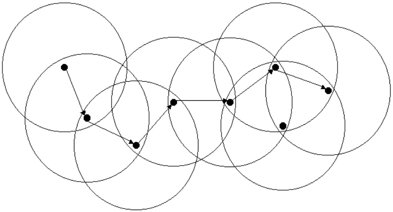

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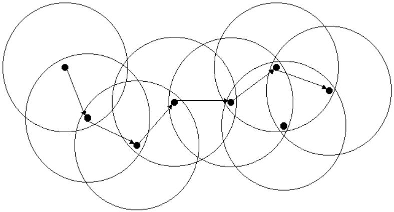
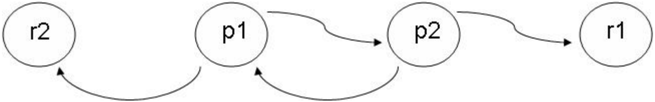


Selfish Behavior of Wireless Nodes

- nodes are owned by individuals in many applications
- source nodes communicate with far off destinations by using intermediate nodes as relays
- limitation of finite energy supply concerns the nodes to relay packets for other nodes
- if every node behaves selfishly, throughput of individual nodes go down
- tradeoff between throughput and resources of nodes such as battery energy, CPU cycles, bandwidth, etc.

Forwarder's Dilemma



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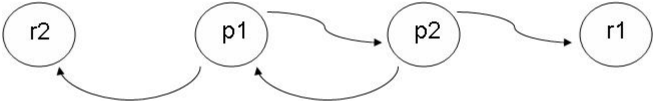

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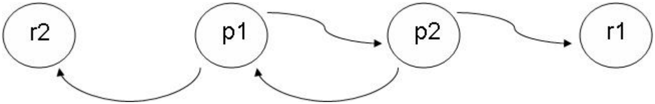

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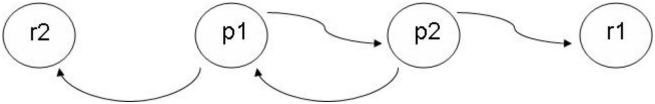

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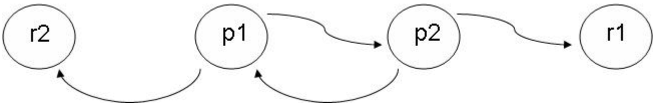

- $p1$ wants to send a packet to $r1$ and $p2$ wants to send a packet to $r2$
- value of communication for both nodes is 1 unit
- forwarding incurs $p1$ and $p2$ a fixed cost $0 < c < 1$ units
- utility to each node: $(1 - c)$
- *Dilemma:* Each node it tempted to drop the forwarding packet to save its resources such as battery power, CPU cycles, bandwidth resulting in *zero* utility. But they could do better by relaying packets.

Observation

Consequence of Rational Behavior of Nodes

Rational behavior of a node suggests that forwarding the transit traffic is not a best strategy, since the forwarding activity consumes its own resources.

Mechanism Design Approach is a Solution

- cooperation among nodes in terms of forwarding packets can be triggered, if nodes are reimbursed appropriately to compensate the incurred costs

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- nodes may not announce their true incurred cost since they are rational and intelligent
- by providing incentives to the nodes appropriately, we can make them reveal their true costs
- Game Theory and Mechanism Design are useful to address the problem

Modeling Ad hoc Networks as Games

Components of a Game	Elements of ad hoc network
players	wireless nodes
strategy	decision to forward
utility function	performance mesures

Incentive Compatible Broadcast (ICB) Problem

- broadcast is useful in many contexts such as route discovery, paging a particular host, sending alarm signal
- successful broadcast requires appropriate forwarding of packets by nodes
- need to provide incentives to compensate the forwarding costs of the nodes
- an incentive mechanism needs to be built into the broadcast protocol
- we refer to the problem of designing robust broadcast protocols with appropriate incentive schemes as *Incentive Compatible Broadcast (ICB)* problem

Relevant Work

- incentive compatible unitcast (or truthful unicast) and incentive compatible multicast (or truthful multicast) problems exist already

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  - no notion of intermediate nodes
  - all nodes are intended recipients except the source

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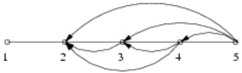
- several mechanism design based solutions are proposed based on VCG mechanisms
- ICB problem is different from incentive compatible unicast and multicast !!!!!
  - no notion of intermediate nodes
  - all nodes are intended recipients except the source
- borrowing solution techniques from incentive compatible unicast and multicast problems may lead to inefficient solutions to the ICB problem



Limitations of the VCG Based Protocols

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- *Limitation 1:* network needs to be bi-connected to design the incentive mechanism

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- *Limitation 2:* may not be self-sustaining

Bayesian Setting for ICB Problem

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Bayesian Setting for ICB Problem

- network need not be bi-connected
- self sustaining protocols can be designed
- cost of the protocol is less
- payment computations can be done in a single round

Our Goal

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Our Goal

Design of an incentive mechanism for the ICB problem using Bayesian incentive compatible mechanisms and build it as part of the broadcast protocol for ad hoc wireless networks with rational nodes

Such a broadcast protocol is called *Bayesian Incentive Compatible Broadcast (BIC-B)* protocol

The Model for ICB Problem

- ad hoc network is modeled as *node weighted* graph
- similar to our mechanism design framework developed so far
- *assumption:* types of the nodes are statistically independent

Important Results

Payment Rule

$$t_i(\theta) = \left(\frac{1}{n-1}\right) \sum_{j \neq i} E_{\theta_{-j}} \left[\sum_{l \in R,\, l \neq j} \theta_l\right] - E_{\theta_{-i}} \left[\sum_{l \in R,\, l \neq i} \theta_l\right]$$

- the payment rule is such that $\sum_{i=1}^{n} t_i(\theta) = 0$

An Illustrative Example

- a linear network with $N = \{1, 2, 3, 4\}$ being the set of nodes

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- types of nodes are their incurred costs
- assume the type sets of nodes are discrete for ease of understanding. $\Theta_1 = \{10, 11\}$, $\Theta_1 = \{15, 16\}$, $\Theta_1 = \{12, 13\}$, and $\Theta_1 = \{7, 8\}$

An Illustrative Example

Computation of payment to node 1:

$$
\begin{aligned}
t_1(\theta) &= \left(\frac{1}{4-1}\right) \sum_{j \neq 1} E_{\theta_{-j}} \left[\sum_{l \in R,\, l \neq j} \theta_l\right] \\
&\quad - E_{\theta_{-1}} \left[\sum_{l \in R,\, l \neq 1} \theta_l\right] \\
&= \left(\frac{1}{3}\right) \left[E_{\theta_{-2}} \left[\sum_{l \in R,\, l \neq 2} \theta_l\right] + E_{\theta_{-3}} \left[\sum_{l \in R,\, l \neq 3} \theta_l\right]\right] \\
&\quad + \left(\frac{1}{3}\right) \left[E_{\theta_{-4}} \left[\sum_{l \in R,\, l \neq 4} \theta_l\right]\right] - E_{\theta_{-1}} \left[\sum_{l \in R,\, l \neq 1} \theta_l\right] \\
&= \left(\frac{1}{3}\right) \left[E_{\theta_{-2}} [\theta_3] + E_{\theta_{-3}} [\theta_2] + E_{\theta_{-4}} [\theta_2 + \theta_3]\right] \\
&\quad - E_{\theta_{-1}} [\theta_2 + \theta_3] \\
&= \left(\frac{1}{3}\right) \left[E_{\theta_{-2}} [\theta_3] + E_{\theta_{-3}} [\theta_2] + E_{\theta_{-4}} [\theta_2] + E_{\theta_{-4}} [\theta_3]\right] \\
&\quad - \left[E_{\theta_{-1}} [\theta_2] + E_{\theta_{-1}} [\theta_3]\right] \\
&\qquad\qquad \text{(since types are statistically independent)} \\
&= \left(\frac{1}{3}\right) [12.5 + 15.5 + 15.5 + 12.5] - [15.5 + 12.5] \\
&= -9.33
\end{aligned}
$$

An Illustrative Example

- Similarly we can compute the payments to the remaining nodes:
  - $t_2(\theta) = 11.33$
  - $t_3(\theta) = 7.33$
  - $t_4(\theta) = -9.33$

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  - $t_2(\theta) = 11.33$
  - $t_3(\theta) = 7.33$
  - $t_4(\theta) = -9.33$
- Now sum of the payments is:

$$\begin{aligned}\sum_{i=1}^{i=4} t_i(\theta) &= -9.33 + 11.33 + 7.33 - 9.33 \\ &= 0.\end{aligned}$$

Payments to Non-Router Nodes

Lemma 1

For any $i \in R$ and for any $j \notin R$, we have

$$E_{\theta_{-i}}\left[\sum_{l \in R,\, l \neq i} \theta_l\right] = E_{\theta_{-j}}\left[\sum_{l \in R,\, l \neq i} \theta_l\right]$$

Lemma 2

In the *BIC-B* protocol,

$$t_i(\theta) = \left(\frac{1}{n-1}\right) \sum_{j \in R} (\Upsilon_j - \Gamma) \;\; < \;\; 0, \; \forall i \notin R, \; \forall \theta \in \Theta.$$

That is, non-router nodes pay for receiving the packet.

Lemma 3

The payments by the non-router nodes, i.e., $t_i(.)$, $\forall i \notin R$ are all the same.

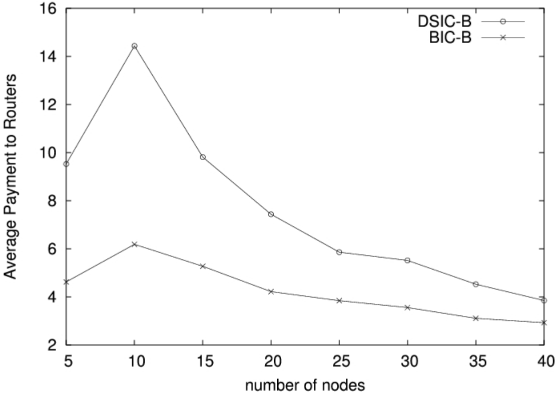
Optimality of the BIC-B Protocol

Theorem 1

If the given SRBT is optimal for the underlying graph G of the ad hoc wireless network under consideration, then the BIC-B mechanism minimizes the payment to be made to each node

Experimental Analysis

Average Payment Ratio (APR): Average payment to the routers for forwarding packet(s)



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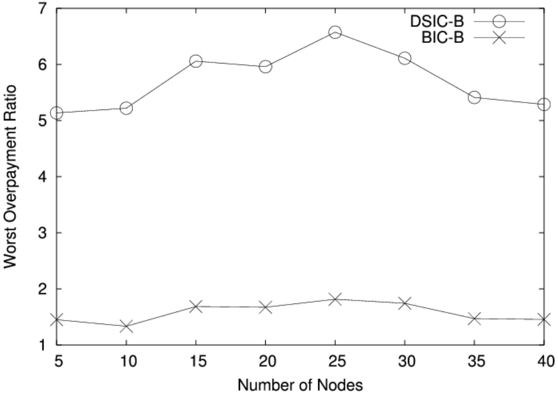
Motivation
An Illustration
Modeling as Game
Broadcast
Relevant Work
Limitations
Bayesian Setting
Goal
The Model
Important Results
Simulations
Conclusions
Future Work

Worst Overpayment Ratio (WOR): $max_{i \in N}$ (Ratio of payment made by node i to its least cost path from s)



Conclusions

- the problem of designing an incentive mechanism for the broadcast task (ICB problem) in ad hoc wireless network is considered
- a Bayesian incentive compatible mechanism is developed
- BIC-B protocol has several nice properties such as equal payments to all the non-routers

Future Work

- how to go about with the prior probability distributions? Jason D. Hartline, *Optimal Mechanism Design without Priors*
- it would be interesting to design a distributed algorithm for the payments computation in BIC-B protocol since ad hoc wireless networks are distributed in nature
- another pointer for future work would be to explore the design of Bayesian incentive compatible protocols for the truthful unicast problem and truthful multicast problems

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