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Pricing to Improve Cooperation in Wireless Ad Hoc Networks

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Abstract Multimedia service requirements are growing because of the adoption of many characteristics of wireless ad hoc networks. However, communications in wireless multi-hop ad hoc networks rely on nodes cooperating with each other. Albeit that good teamwork could smoothly run such a mobile network, selfish node behaviors would probably cause it to break down. To cope with this problem, we devise a non-cooperative node game model (NCG) based on requirements of the nodes' packet sending and the forwarding probabilities for other nodes. NCG uses a pricing mechanism to mediate the conflicting between source node and relay node: the source node pays the relay nodes using two different money-related utility functions that trades off the payoff for the relay nodes.

Keyword Selfish node, Game Theory

1. Introduction

Multimedia service requirements are growing because of the adoption of many characteristics of wireless ad hoc networks. Wireless ad hoc networks try to make all their nodes participate in performing the network functions, but some nodes may use a probabilistic "wait and see" approach; that is, they try to avoid forwarding packets by waiting for a certain time to see if other nodes pick them up instead.

Earlier work [1][2][3] has shown that such non-cooperative behavior could easily degrade the network's performance. However, the dynamic interactions arising in ad hoc networks make it difficult to analyze and predict node performance, and thus, this difficulty can be seen as inhibiting the development of wireless ad hoc networks. Recently, many researchers have become interested in using a pricing scheme based on game theory to stimulate nodes in mobile ad hoc networks to cooperate [2], [4], [5], [7]. An efficient pricing mechanism makes decentralized decisions compatible with overall system efficiency by encouraging less aggressive sharing of resources rather than the aggressive competition of the purely non-cooperative game. A pricing policy is called incentive-compatible if it improves the sum of all nodes utilities [6] [7]. Although such pricing schemes achieve maximal throughput or power control for the whole system, some policies are extreme and we think they do not account for the relative preferences for individual nodes. Typically, pricing should be motivated by two different objectives: 1) it generates revenue for the system, and 2) it encourages players to use system resources more efficiently. However, most of the previous work has focused on the first aspect of this problem. In our work, we focus on both aspects: we motivate individual nodes to adopt a cooperative strategy that not only guarantees the whole system performance, but also satisfies their own service requirements. Once the service requirements of the individual nodes have been satisfied, the profit from selfish behavior becomes low.

In this paper, we discuss a pricing policy to avoid non-cooperative behavior incorporating a "pay and compensation" scheme in a game-theoretic framework. This scheme balances the amount of service a mobile node provides with the amount of help it receives. We assume that when one node sends packets as a source node, it must pay a price (e.g. they pay money to send). If we think of the implied money as the penalties to be paid by the source nodes, in order to induce voluntary forwarding, the nodes who forward packets for other nodes could be compensated (also e.g. the receive money to forward).

2. Packet Forwarding in Ad Hoc Networks

2.1. System Description

Mobile nodes access a wireless network through the air interface, which is a common resource, and each node's transmission is a source of interference for others. Let us consider that the transmission radius is assumed to be identical for all nodes. Each node has a given power range, and two nodes are said to be neighbors if they reside within each other's power range. Communication between two non-neighboring nodes is based on multi-hop relaying. That means a node can only directly communicate with its neighbors; thus, the packets may be relayed over multiple nodes before the destination node is reached. A single path of nodes from the source to the destination is called a route. However, we assume that a node could not send and receive packets at the same time. We assume that the route from the source node to the destination node has been determined first (using some existing routing protocols like DSR). We also assume CBR packets in our work, which means each source node generates packets at a constant bit rate in each route. However, this rate may be different in the different route.

2.2. Packet forwarding on one S-D pair

We consider a given route (Fig.1) between the source node S and the destination node D of the form *(S, r1, r2 ,..., rj ..., rm, D)*, where rj is the jth relay node and *m* is the number of relay node on the route.

Since we are studying cooperation in packet forwarding, we assume that the main reason for packet losses in the network is the non-cooperative behavior of the nodes. (Network congestion is negligible in our study.)

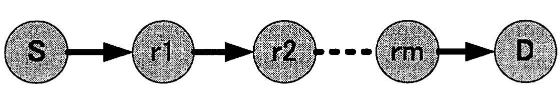

Fig.1 Source-destination pair

For the given route (*S, r1, r2,... , D*), suppose that each relay node rj choose a cooperation level $p_{rj} \in [0,1]$, where p_{rj} is assumed to be the probability that the packet is forwarded by the relay node rj (independently from the source of the packet). Cooperation level 0 and 1 represent full packet drop and full packet forwarding. The probability that a transmitted packet reaches its destination is thus:

$$P(S, r1, r2,..., D) = p_{r1} * p_{r2} * ... * p_{rm} \quad (1)$$

The throughput $\tau(S, r1, r2, ... ,D)$ in the route *(S, r1, r2, ..., D)* is defined as the fraction of packets sent by the source node S that are delivered to the destination node D:

$$\tau(S, r1, r2, ..., D) = x_s * P(S, r1, r2, ..., D) \quad (2)$$

Where x_s denotes the constant traffic that source node S wants to send to the destination node D on the route *(S, r1, r2... D)*.

3. Model of a Non-cooperative Node Game and Analysis

3.1. Game in Strategic form

Here, we briefly introduce that a strategic game {N, Xi, Ui} that has three components: a finite set N = {1, 2, ..., n} of players, a strategy space (Xi, i 2 N)and a utility functions Ui for player i. Each player selects a strategy xi from Xi. X denotes the set of the strategy vectors for all players. The utility function Ui models player i final utility defined on strategy space Xi.

3.2. A Non-cooperative Node Game

For convenience of analysis, we model one source-destination pair as one-round game, called NCG.

Players. The players in the game are the source node S and the relay node r1, r2, ..., rj,.. rm.

Strategies.

Source node S: the strategy of the source node S is the money m_s it wants to pay for the relay nodes in the route *(S, r1, r2, ..., D)*, $0 \le m_s \le m_{sb}$,m_{sb} represents the budget constraint of the node S.

Relay node rj: chooses the packet forward probability p_{rj} , $0 \le p_{rj} \le 1$.

Cost.

Source node S: the cost is the total payment for the relay nodes $C(m_s) = \sum_j C(rj)$

Relay node rj (Fig.2): the cost is the packet forwarding cost C(rj). We let $C(rj)=\alpha*(c_{rj} * \delta_{rj} * p_{rj})$, where δ_{rj} is the packets arrive at node rj, Each relay node rj has an individual parameter c_{rj} that indicates its unit energy cost for forwarding a packet. The parameter value of c_{rj} is dependent on the left battery of the node, so it may change over time. The pricing factor α can be considered as the corresponding money cost for recharging the unit battery. C(rj) represents the final money cost for rj to forward the packets from the source node S.

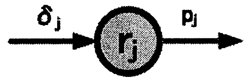

Fig 2 Model of the relay node rj

Utility. In the analysis, we assume only source node S benefits if its packets successfully reach the destination node; relay node rj loses benefits if it forwards packets for other nodes and the benefit for the destination node is assumed to be 0 (an example of our assumption is file upload, and the model would be extended with benefit of the destination node in the future).

Source node S: The utility for the source node S is to maximize the throughput on S-D pair:

$$\max\{U(x_s\prod_j p_{rj})\}$$

Relay node rj: The utility for the relay node is the money gained from the source node S, defined as *U(rj)*.

Payoff

Source Node S: the payoff is $J_s = U(x_s\prod_j p_{rj}) - C(m_s)$, where $U(x_s\prod_j p_{rj})$ represents the utility for the source node S when the packets successfully reach the destination node; $C(m_s)$ represents the total money spent on the relay nodes. Given the budget constraint, the motivation of the source node S is to

$$\max_j\{U(x_s\prod_j p_{rj}) - C(m_s)\}$$

Relay node rj: the payoff is $J_{rj} = U(rj) - C(rj)$, where *U(rj)* is the gained payment and *C(rj)* is the forward cost. Given the left energy constraint, the motivation of the relay node is to

$$\max_j\{U(rj) - C(rj)\}.$$

However, this payoff requires that for any relay node on the S-D pair, the final gained payment should be greater than the forward cost. The condition is necessary because that if the compensation payment is equal to the cost, it is impossible for the relay node to be cooperative in the game.

3.2. Analysis of NCG Model

Since the money payment is provided by the source node S, it is possible to use various utility functions. The objective of the payment is to find a feasible p_{rj} vector that satisfies some performance requirement. In our case, the source node S wants to maximize the throughput on S-D, a high value of p_{rj} ill be favored.

Meanwhile, the relay node rj is willing to accept the money to forward the packets and it is selfish: it wants to maximize its total payoff. From reference [9], a series of concave utility function can be used: here we choose two utility functions:

1. We let utility function $U(rj) = \omega_{rj} \cdot e_{rj}$, where $e_{rj} = c_{rj} \cdot \delta_{rj} \cdot p_{rj}$, ω_{rj} is the weight factor between [0,1], subject to: $\sum_j \omega_{rj} c_{rj} p_{rj} \delta_{rj} \le m_s$

2. We let utility function $U(x) = \log(x+1)$, as it satisfies the proportional fairness and guarantees $U(x) = 0$, at $x = 0$.

Definition 1: For the relay node, an optimal strategy is a strategy that brings maximal payoff to it, regardless of the strategies of all the others.

4. Implementation

This implementation addresses three parts:

1. Routing stage: determines a packet forwarding path from a source to a destination (assume DSR);
2. Forwarding stage: verify that forwarding does happen;
3. Payment stage: charges the source node and pays the relay node.

Source Node: Sending a packet.

Suppose that node S is to send xs with sequence number *seq*0(S, *D*) to destination D. Node *S* transfers (x_s, τ, *seq*(S,*D*), *S*) to the next hop, and increases *seq*0(S, *D*) by 1.

_ x_s is the packet generated by source node.

_ *S* is the sender, D *is* the destination, and τ *is* the route.

Steps

sends (x_s, τ, seq0(S, D), S) to the next node *seq*0(S, *D*) + +

updates $C(m_s)^{(k+1)}=C(m_s)^{(k)}-M$

_*M* is the total money pre-paid for the relay nodes.

Relay node: Receiving a packet.

Suppose that the relay node r*j* receives (*xs, p, seq, S*). It first checks two conditions: 1) *rj* is on the path; 2) the packet has a sequence number greater than *seqj* (0,*D*). If any of the conditions is not satisfied, the packet is dropped. If r*i* is not the destination and decides to forward the packet, it sends (xs, τ, *seq, S*) to the next hop.

Steps.

_ (xs, τ, *seq,Ss*) is the received packet.

_ *S* is the source, D the destination.

if ((rj not in τ) // (*seq* _ *seqj*(0, *D*))

drop the packet

else

seqj(S, *D*) _ *seq*

save (x_s, τ, *seq, S*) as a receipt

if (r*i* is not the destination **and** decides to forward)

sends (x_s, *p, seq, S*) to next hop

else

drops the packet

Node rj receives (x_s, τ, *seq,S*).

4. Performance Evaluation

For the simulation, we evaluate NCG model using NS2. Our model is implemented on top of DSR routing protocol

4.1 Simulation Setup

The setup consists of 30 nodes that are uniformly distributed in an area of 2000*2000 meters, all nodes are static, and the ID of the nodes is labeled in Fig.3.

Radius range of each node is 250 m. We use 802.11b as the Mac layer (2Mbps). Initial Energy is set 1000.0, transmission power is set as 0.6, receive power is set as 0.2. Original budget of each node is set 300 to each node. c_{rj} is set 1. We study utility function 1 $U(rj)=\omega_{rj}\cdot e_{rj}$, where $\omega_{rj}=1$

We generate traffic randomly. The start of an S-D session at a node is CBR traffic. Packet size is randomly chosen from 1~10 1024byte/s. The expected time interval between two sessions from the same node is 60s. The relay and destination node is picked randomly from the left nodes.

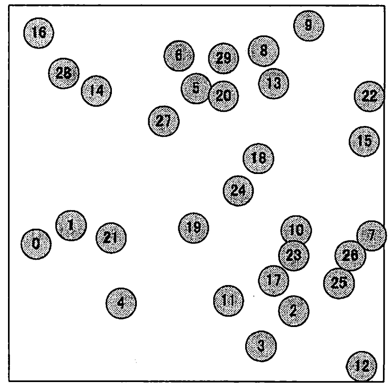

Fig. 3 A network with 30 nodes.

4.2. Simulation Metric

We start the simulation by observing the two evaluation metrics.

Money balance= total money received by forwarding others' traffic minus the total money paid by sending one's own traffic.

Energy cost= the accumulating energy the nodes spent in forwarding others' traffic.

4.3. Result Analysis

As our simulation assumes a high money budget and energy life at the beginning of the evaluation, each selected node could always forward the packets if doing so can maximize its payoff, and always generates packets. So we observed that both the money balance and energy cost of some nodes increase monotonically. We also observe from Fig.4 and Fig.5 that the nodes accumulating more credits also spend more energy in forwarding others' traffic, which verifies that our model is fair.

5. Conclusion

We established a framework that uses game theory to provide incentives for non-cooperative nodes to collaborate in the case of wireless ad hoc networks. The incentive scheme proposed in the paper is based on a non-cooperative node game *(NCG)* that can be implemented in a completely distributed system. Using *NCG*, we showed that the node's behavior could be influenced through the introduction of the "pay and compensation".

However, relay node rj can misreport its cost of forwarding as *C'ri --> Cri*. So the game rule should be modified such that being truthful is the dominant strategy. We should study the proposed model in the context of different measurement scenarios. In our future work, we also want to discuss the conditions under which integration of nodes are interested in forming small non-cooperative groups.

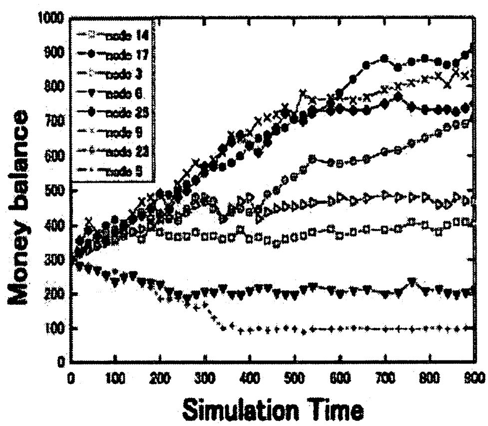

Fig.4 Money balance

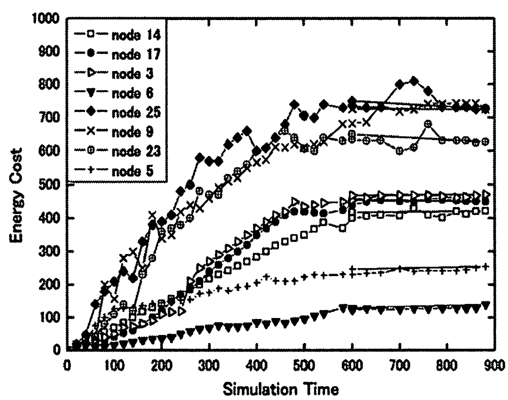

Fig.5 Energy cost

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