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A Routing Protocol using Game Theory in Wireless Ad Hoc Networks

***Abstract**. Wireless ad hoc networks (WAHN) with easy maintenance, self-organization and management capabilities, and low cost properties will play a great role in the continued development of new commercial applications. We propose a routing protocol using game theory applied to the routing within the highly independent wireless ad hoc networks. However, the development of each network node's routing cost must be in line with Nash equilibrium. We use the VCG mechanism to assess and calculate the network route, the minimum cost routing path with the shortest route.*

***Streszczenie.** W artykule zaproponowano protokół routowania, wykorzystujący teorię gier dla niezależnych sieci bezprzewodowych ad hoc. W celu utrzymania równowagi Nasha w kosztach routowania korzeni sieci, zastosowano mechanizm VCG. Pozwoliło to na wyznaczanie najmniej kosztownego sposobu routowania . (**Wykorzystanie Teorii Gier w protokole routowania w sieciach bezprzewodowych ad-hoc**).*

Keywords: WAHN, .Game Theory, VCG
Słowa kluczowe: WAHN, Teoria Gier, VCG.

1. Introduction

In a network infrastructure, most nodes are from the same established Internet service provider. From the network architecture point of view, network routing design is based on the maximum performance of the overall network without regard to the node ‘owner’. In the wireless ad hoc network framework the relationship between nodes does not consider if the node is from the same network service provider. Because each network node is independent, they will actively search for the information they need and provide services throughout the network. These autonomous nodes pursue overall network performance but they must also focus on the situation between the nodes in order to accurately reflect the reality of the network environment [1,2].

A game is made up of three basic components: a set of players, a set of actions, and a set of preferences. The players are the decision makers in the modeled scenario. In a wireless system, the players are most often the nodes of the network. The actions are the alternatives available to each player. In dynamic or extensive form games, the set of actions might change over time. In a wireless system, actions may include the choice of a modulation scheme, coding rate, protocol, flow control parameter, transmit power level, or any other factor that is under the control of the node. When each player chooses an action, the resulting action profile determines the outcome of the game [3].

Game theory is designed to allow participants in the Game to get the most benefits. The idea is, if the participants have a distinct strategy with both competition and cooperation in complex cases and if game theory can really balance the interests of all participants in the solution, why not develop a wireless network game Bureau? This game Bureau will search for a process to allow all nodes to meet their needs strategy. This research will focus on designing a proper response to the node cost, finding the minimum cost path and using a feedback mechanism to stimulate the network routing scheme. Game theory will be used to more precisely define the characteristics of wireless ad hoc network routing [3].

2. Game Theory

The broad definition of game theory is a collection of case studies to develop mathematical models of conflict and cooperation. In this case, it will be used to seek the best routing method and allow decision-makers to understand the stability and outcome. In general, game theory studies the conflict of interest between the parties to select the most appropriate response strategy. The participant estimates the outcomes from the chosen strategy, and seeks his own best chance of winning or benefiting from the competition. In the definition of game theory, the object of study can be any reasonable circumstances. Namely [4]:

- Participants: There are two or more decision makers, known as the participants. Participants may also be known as players. Players can be individuals, groups or as in this paper, wireless nodes. The Game is to maximize their own interest by a decision-making process.
- Game rules: Participants in the Game may agree on the rules to be observed and this decision determines the strategy. Different Games have different rules, for example, in golf the player who completes all the holes with the least number of strokes is the winner; in figure skating competition several reviewers rate the participants based on their skill and art and the sum of these subjective ratings determines the winner.
- Strategy: Refers to the action selection rules used by the participants. Each participant may have two or more strategies that determine their behavior under various circumstances. That is, under any set of conditions, participants should choose an action to ensure their own maximum benefit. Participants may use the same or different sets of strategies.
- Pay: Each participant will have a range of possible outcomes and a clear order of preference based on the payment.

Game theory explores how participants play any game. All participants seek the most favorable results when the game ends. Therefore, the strategy chosen by participants in the Game will affect the results and the outcome of the Game depends on the strategies of all participants. Contestants may choose either conflict or cooperation with different results for each choice. Thus game theory can often be divided into a cooperative game or a non-cooperative game [5].

3. Routing protocols using game theory

3.1 Routing Game Model

First, consider the establishment of a network with n nodes connected by wireless links in an Ad Hoc network. Assume a bi-connected and symmetric network topology. In other words, if network node A has wireless connection capabilities to the network node B, then the network node B will have the same ability to link to wireless network node A.

Game routing definition: During the process of finding the best route from the source node to the destination node by a series of steps using intermediate nodes for all participants in the network, the wireless network architecture is a routing Game. Now divide the nodes in the route into three categories: the source node ν_S, the intermediate node ν or ν_k, and the destination node ν_D.

Next, assume that all nodes are honest and willing to pay a fixed set of route prices. For example, the source node $\nu_S$wants to transmit data to the destination node ν_D, and how much it is willing to pay for routing the data to the destination node, only it knows and the other nodes have no way to know this fixed price. Assume that each node can determine its own needs and set its own maximum price.

Suppose $P_{willing-to-pay}$ is the maximum price the source node v_S is willing to pay to transfer a packet, then we define the source node v_S utility function as

(1) $$U_S = P_{willing-to-pay} - C_s(v_D)$$

In the previous mathematical formula, $C_s(v_D)$ represents the cost for transferring a packet from node v_S to node v_D. If the routing path does not exist, then U_s must be equal to zero.

Next, consider the intermediate node v, with information known only to itself which sets prices accordingly as C_v. The information node v may use includes distance to neighboring nodes, power available, bandwidth, range, or other factors. In the simulation, simply assume price C_v to the neighboring node $l(v)$ system is the delay time $C_v = l(v)$. Thus when the time delay is long, the price will increase.

The intermediate node also has a utility function $u_v = p_v - l(v)$. Node v_S is required to pay the cost of v forwarding a single packet, where the cost can be expressed as p_v, if v is not in the data transmittal routing path, then $p_v = 0$.

3.2 Pricing mechanism

Suppose a source node to destination node cost $c(P)$ for path P, $c(P) = \sum_{v \in P, v \notin \{v_S, v_D\}} l(v)$ in the proposed routing protocol. The path chosen must be the minimum or least cost path (LCP). For any intermediate node v on the LCP, use $c(P^{-v})$ for the cost of a path which bypasses a node included in the LCP. Based on the previous assumptions, the network topology of the link is bi-connected, so that the path P^{-v} must exist. Therefore, node v needs to receive payment $pay(v)$ given by

(2) $$pay(v) = c(P^{-v}) - c(LCP) + l(v)$$

Finally, determine the package cost $C_s(v_D)$ which the source node v_S will have to pay. In short, choose $\sum_{v \in LCP, v \notin \{v_S, v_D\}} pay(v)$ as a way to calculate the cost, but this approach will have some problems. Figure 1 helps to explain the problem.

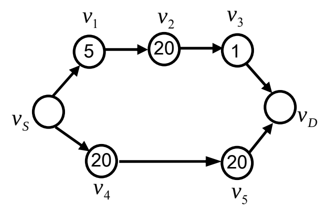

Fig. 1 $\sum_{v \in LCP, v \notin \{v_S, v_D\}} pay(v)$ as an example of using $C_s(v_D)$

From fig. 1 LCP={ν1,ν2,ν3} c(LCP)=26. Inserting c($P^{-\nu1}$) =C($p^{-\nu2}$)=C($p^{-\nu3}$)=40 $c(P^{-v_1}) = c(P^{-v_2}) = c(P^{-v_3}) = 40,$ into $P_{willing-to-pay}$ = 65 formula (2) for calculation, then for nodes ν_1, ν_2 ν_3 and, the payments are as follows

$$pay(v_1) = 40 - 26 + 5 = 19$$
$$pay(v_2) = 40 - 26 + 20 = 34$$
$$pay(v_3) = 40 - 26 + 1 = 15$$

After calculation, the total price of $19 + 34 + 15 = 68 > 65$ is more than the node v_S ‘willing to pay price’, so this path will not be accepted. Now let assume that node v_2 increases its price to 30. Once again, re-calculating what v_S needs to pay for the new path v_1, v_2, and v_3, the price is as follows:

$$pay(v_1) = 40 - 36 + 5 = 9$$
$$pay(v_2) = 40 - 36 + 30 = 34$$
$$pay(v_3) = 40 - 36 + 1 = 5$$

After the price of node v_2 is increased to 30, the calculated total cost becomes $9 + 34 + 5 = 48 < 65$. This price is less than the ‘willing to pay’ price but it is not actually a reasonable price for node v_2. This violates the requirements of our routing protocol: the price set by each node must be able to reflect the real cost required by the node.

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Now consider another new idea: If the presence of v_k on the LCP will be determined by how the price of v_k impacts $C_s(v_D)$, then does a path P^{-LCP} exist which does not include any of the LCP nodes, and what is the total cost of the $C_s(v_D)$ to replace the original LCP? The answer is yes. This is how a Vickrey auction works: use the second as a price to pay for the total price. This path, called the general alternative path, is used mainly to rule out an excess price by any intermediate node on the LCP.

3.3 Routing algorithm

The proposed routing algorithm can be divided into two stages: route discovery and data transmission. The algorithm takes full advantage of Hello messages between nodes in the RTT (round trip time) to use as $l(v)$ value.

When the source node v_S needs to find the destination node v_D, it will generate a route request (RREQ) packet, and use broadcast transmission. This packet not only includes the source node and destination node address information, it also has unique information, that is $P_{willing-to-pay}$. If it can find an immediate path to the destination node and the total cost of $C_s(v_D)$ is less than $P_{willing-to-pay}$, then the source node can start sending packets and pay the cost for each intermediate node of v_k. As for the intermediate node v_k, it receives the RREQ format as follows:

(3) $$RREQ[v_S, v_D, ...P_{willing-to-pay}, l(v_1), ..., v_{k-1}, l(v_{k-1})]$$

The $v_1, ..., v_{k-1}$ in the preceding equation represents the path from the source node to the node v_{k-1}, and $l(v_1), ..., l(v_{k-1})$ represents the payments to the intermediate nodes. When each node v_k receives this packet, it will include its own private message v_k in the packet in the corresponding field and $l(v_k)$ will continue to broadcast. This action will continue until the packet reaches its destination node.

3.4 Routing Cost

In LCP, the selected path aims to minimum accumulated cost of paths calculation. As previously mentioned, the major benefit of LCP is to search the shortest path as well as minimum routine cost.

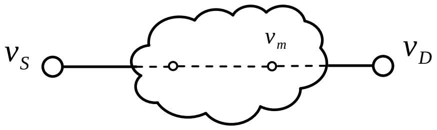

Fig. 2. Evaluating architecture of LCP routing cost

The cost of each path is given by the following equation,

(4) $$C_{LCP}(v_k | v_k \neq v_S) = \sum_{(v_{k \to m}) \in (v_S \underset{Paths}{\to} v_D)} C_{rc}(v_k) \times (E_t + E_r)$$

where v_i denotes intermediate node, v_S denotes source node, v_D denotes destination node, C_{rc} denotes routing cost, E_t denotes required energy to transmit packet from source, E_r denotes the energy required by the destination which receives each packet, and $(v_S \underset{Path}{\to} v_D)$ denotes the selected shortest path that accumulates cost from node v_S to node v_D . An erroneous cost estimate could result because the routing cost of nodes is dependent on the remaining energy of a node and an adjacent node rather than completely from the node itself, for instance, to select and to value a dying node as a low cost routing path. In this paper, for long-term efficacy of LCP, we do not discuss how to avoid or select the remaining lacking energy of an adjacent node [6].

4. Experimental simulation and data analysis

4.1 Packet delivery ratio

In figure 4 the result is presented for 40 pairs of S-D pairs simulation. When the S-D pairs were increased from 10 pairs to 40 pairs, even at low pause time (low mobility), the proposed routing protocol obviously has a higher packet delivery ratio.

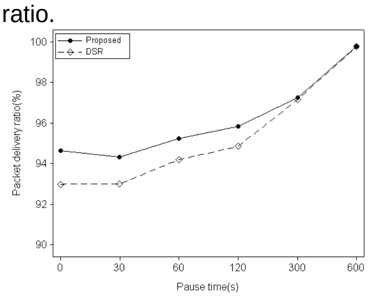

Fig. 3. Packet delivery ratio (40 source-destination pairs)

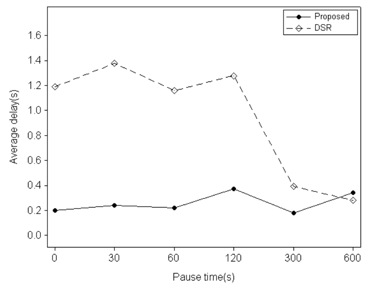

Fig. 4. Average delay (40 source-destination pairs)

4.2 Average delay

When the number of S-D pairs was increased from 10 pairs to 40 pairs, the proposed method is superior to DSR, especially in the case of delays less than 120 seconds.

4.3 Routing Cost

Similarly, we use the NS-2.29 simulator with the system default parameters to determine the routing cost. During the simulation, use the LCP and the minimum energy cost to calculate the routing cost.

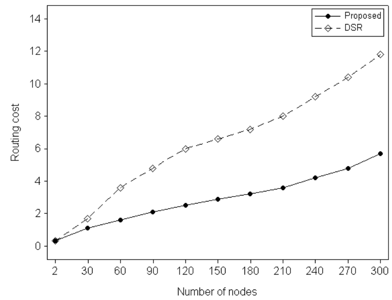

Fig. 5. Simulation result of packets routing cost. (Nodes speed remaining at 30 km/hr)

5. Experimental simulation and data analysis

This research applied game theory from economics to ad hoc wireless networks and transformed the route into a routing game to solve the above problems. In the paper, the proposed structure requires the other nodes in the data transfer to be paid for transferring the data and requires all participating nodes to decide on the costs and rewards. This paper used game theory to develop a protocol for paying reasonable prices for data packet transmission. This protocol rewards reasonably priced intermediate nodes and avoids overpriced nodes. If the method proposed in this paper is enlarged by adding QoS considerations and power loss assessment as node pricing considerations, the proposed method will lead to more efficient routing

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