On Game Theory for Load Balancing in Wireless Networks

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***Abstract*—We study the problem of balancing the load of the nodes in wireless networks. A node to node communicating network with a uniform distribution of source destination pairs is assumed. When routing along shortest paths, the nodes which are located near the center of the network forward high amounts of traffic. Also the nodes near the periphery areas carry low amounts of traffic. In this paper, we analyze this problem and propose a practical method, inspired by game theory, for solving it. Also, the proposed method is applicable on the networks with arbitrary topologies. Our results suggest that this is an effective method for balancing the load of the nodes in wireless networks.**

I. INTRODUCTION

During the last few years we have all witnessed persistently increasing growth in the deployment of wireless networks. Several types of wireless multihop networks exist with different unique characteristics [1]. These include mobile ad hoc networks (MANET), wireless mesh networks (WMN) and wireless sensor networks. A mobile ad hoc network is a temporary network, without any infrastructure, formed by a set of wireless mobile nodes that dynamically establish the network, without relying on any central administration. As various wireless networks evolve into the next generation, ad hoc networks have evolved to wireless mesh networks to form a novel mobile wireless multi-hop network. In WMNs, nodes are divided into two categories including mesh routers and mesh clients. Each node operates not only as a client but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. In WMNs, mesh routers usually have minimal mobility, while mesh clients can be stationary or mobile nodes. Wireless sensor networks collect some information from a source area and deliver the information to one or more destination areas. These features brings many advantages to wireless networks such as low up-front cost, easy network maintenance, robustness, and reliable service coverage [2].

Due to the limited transmission range of wireless network interfaces, multiple nodes may be needed for one node to exchange data with another one across the network (This is accomplished by mesh routers in WMNs). Routing in wireless networks can be accomplished through either single path or multiple paths. Using single-path routing protocols, traffic is not distributed fairly in different locations of the network. Consider a multi-hop wireless network with uniform node-to-node communication employing shortest path routing. Under these assumptions the center of the network becomes a bottleneck, as more paths go through the center than through the periphery of the network [1], [3], [4]. Thus, the nodes which are located in the center of the network, should carry more amounts of load than the nodes which are located in the peripheral areas. In this paper we analyze this problem and propose a practical method, inspired by game theory, for solving it.

Applying game theory has been proved to be very useful in the context of the internet and wired networks [5], [6]. Here an example is presented to show the use of game theory for analysis of the internet. The Internet is comprised of many individual administrative domains known as Autonomous Systems (ASs). Routing occurs on two levels, intradomain and interdomain. These tow levels are implemented by two different sets of protocols. Intradomain-routing protocols route packets within a single AS. Interdomain routing routes packets between ASs. Although routing is a very well-studied problem, it has been studied by computer scientists from the ”protocol-design” approach. Nisan and Ronen [7] introduce combining of the ”incentive-compatibility” approach with the ”protocol-design” approach to the problem. Internet routing is a natural problem for considering incentives, because ownership and operation give the Internet the characteristics of an economy. Feigenbaum and et al [5] studied the routing mechanism design perspective. They concentrated specifically on interdomain routing. In their formulation of the routing-mechanism design problem, each Autonomous System incurs a per-packet cost for carrying traffic, where the cost represents the additional load imposed on the internal AS network by this traffic. To compensate for these incurred costs, each AS is paid a price for carrying transit traffic, which is traffic neither originating from nor destined for that AS. It is through these costs and prices that consideration of ”incentive compatibility” is introduced to the interdomain-routing framework, which, as currently implemented, does not explicitly consider incentives. Thus, the goal is to maximize network efficiency by routing packets along the lowest-cost paths (LPC). Given a set of costs, the LPCs can be computed using standard routing protocols (such as BGP). However, under many pricing schemes, an AS could be better off lying about its costs;1 such lying would cause traffic to take non-optimal routes and thereby interfere with overall network efficiency. To prevent this, they consider that how one can set the prices so that ASs have no incentive to lie about their costs.

In this paper we assume that nodes are aware of their own locations as well as their neighbors locations. This assumption has important advantages such as scalability, simplicity, and low overhead. Also we want to design a method to minimize the maximum load in wireless networks. According to game theory approach that discussed previously, we assume that each node incur a cost for carrying the data in the wireless network. Also the best path for a source node is to route its data through lower cost paths (LPC). Thus, if the prices of the nodes which are located in the center of the network are higher than the prices of the nodes which are located in the peripheral areas, then the load of the nodes near the center is decreased and the load of the nodes near the peripheral areas is increased and as a result, the load is balanced. It is because the source nodes prefer the paths that have lower costs and these paths are not necessarily the shortest paths. In this paper, we design an algorithm inspired by game theory approach for balancing the load of the nodes in wireless networks. Also we propose an approximation algorithm for finding and assigning the costs to nodes that balances the load. It should be noted that each load balancing algorithm in wireless networks increases the total network load, since shortest path algorithm minimizes the total load. Also we do not have any assumption about the shape and topology of the network. Moreover, there is no conditions on the links between the nodes of the network.

The rest of this paper is organized as follows: section 2 includes a formal statement of the problem. In section 3 a method for finding the costs of the nodes is presented in detail. In section 4, we present our simulation results. Related works are discussed in section 5. Concluding remarks are presented in section 6.

II. Formal Statement of the Problem

The network has a set of nodes N, $n = \|N\|$. There is a set L of (bidirectional) links (edges) between nodes in N. We assume that the wireless network is biconnected because all links in usual wireless networks are biconnected. But this is not a critical restriction, because the route-selection problem only arises when a node has multiple potential routes to a destination. Any two nodes $i, j \in N$ send their data to each other with the uniform distribution where i is the source and j is the destination and vice versa.

We assume that a node k incurs a transit cost c_k for each transit packet it carries. It is assumed that this cost is independent of which neighbor k sends the packet to and which neighbor k received the packet from. It should be noted that this approach could be extended to apply on a more general case. In general case each node has different cost and the cost is depending on which neighbor k sends the packet to, in this case the costs are associated with the edges of the network. We write c for the vector $(c_1, \ldots, c_n)$ of all transit costs of the nodes.

The goal is to send each packet along the LCP, according to the cost vector c. For finding and computing the LCPs, we use the Dijkstras algorithm. Also, we assume that, if there are two LCPs between a particular source and destination, one of them is chosen randomly. This is an appropriate way to break ties. Let $I_k(c, i, j)$ be the indicator function for the LCP from i to j. We set $I_k(c, i, j) = 1$, if node k is an intermediate node on the LCP from i to j, and $I_k(c; i, j) = 0$ otherwise. This is summarized in the following formula.

$$I_k(c,i,j) = \begin{cases} 1 & \text{if node } k \text{ is an intermediate node} \\ & \text{on the LCP from } i \text{ to } j \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

It should be noted that $I_i(c, i, j) = I_j(c, i, j) = 0$. It means that only the transit node costs are counted and the costs of sources and destinations are not considered. Thus, the load of node k, $L(k)$, is equal to $L(k) = \sum_{i \in N} \sum_{j \in N} I_k(c, i, j)$.

Suppose the routes specified by the indicator functions. When the traffic is sent along these paths, each transit node will incur a cost. Node k incurs a cost c_k for a packet sent from i to j if and only if k lies on the selected route from i to j. The total cost u_k incurred by transit node k is equal to $u_k(c) = c_k \sum_{i \in N} \sum_{j \in N} I_k(c, i, j)$. The objective function we want to minimize is the total cost of the network of routing all packets which is equal to $\sum_{k \in N} u_k(c)$. Also, by routing along the LCPs, we want to gain the following purpose.

$$\forall\ i, j \in N : \sum_{p \in N} \sum_{q \in N} I_i(c, p, q) = \sum_{t \in N} \sum_{s \in N} I_j(c, t, s) \tag{2}$$

It means that the load of each nodes i and j equal to each other or $L(i) = L(j)$. In the next section, it will be shown that it is not possible to rout packets in the way that the load of each nodes i and j equal to each other. Thus, the load of each nodes i and j should be equal to each other within an acceptable tolerance. By minimizing the total cost of the network and assigning higher costs to the nodes which are located near the center of the network, the load of the network balances. In the next section the process of finding proper cost for each nodes for balancing the load is presented.

III. Finding the Costs of the Nodes

In this section a method for assigning proper costs to the nodes for balancing the load is presented. According to equation 2, the purpose is to assign proper costs to the nodes that the load of every node in the network equals to the load of other nodes. But it is not always possible to gain this purpose in wireless networks. For example, consider the network in Fig. 1. In this network, nodes B, C, D and E are connected to each other via node A. For routing data from node B to node D, there is just one path. This path contains node A. This is also applied for routing from node E to node C and so on. Thus, the load of node A is very high and the load of other nodes are zero. Also, there is no path routing that balances the load, because there is only one selection for each source to destination communication.

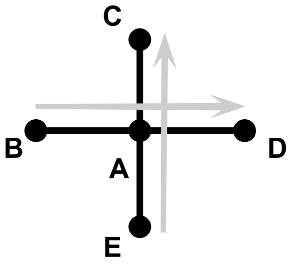

Fig. 1. In this wireless network, nodes B, C, D and E are connected to each other via node A. There is no path routing that guarantees the load of nodes equal to each other.

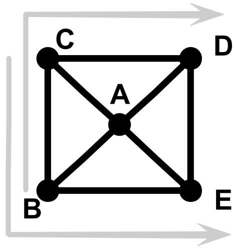

Fig. 2. In this wireless network, nodes B and D and nodes C and E should send their packets to each other via intermediate nodes. There is no path routing that guarantees the load of each node equal to the load of other nodes.

For another example, consider the network in Fig. 2. In this network, nodes B and D and nodes C and E should send their packets to each other via intermediate nodes. We can balance the load using different intermediate nodes but we can not assign costs to the nodes so that the load of each node is equal to the load of other nodes in the network. For example, we can use path BCD for routing between nodes B and D and path CBE for routing between nodes C and E. In this case the load of nodes A, D and E equals 0 and the load of nodes B and C equals 1. But there is not any node with the load equals 2 and the load is balanced with an acceptable tolerance.

Using the above examples, it turns out that it is not possible to assign proper costs to the nodes, so that the load of every node in the network, equals to the load of other nodes. But it is possible to balances the load with an acceptable tolerance. Thus, we have implemented an algorithm for finding the cost vector c. We start with equal costs and at each step we compute lowest cost paths between nodes using Dijkstra's algorithm. Then the load of each node is computed as the number of node to node LCPs that contain it. We then adjust node costs by decreasing those that have smaller than average loads, and increasing those with higher than average load. This process is repeated until the load converges to a common value at all nodes within an acceptable tolerance. The pseudo code for finding the proper costs is presented in Table I.

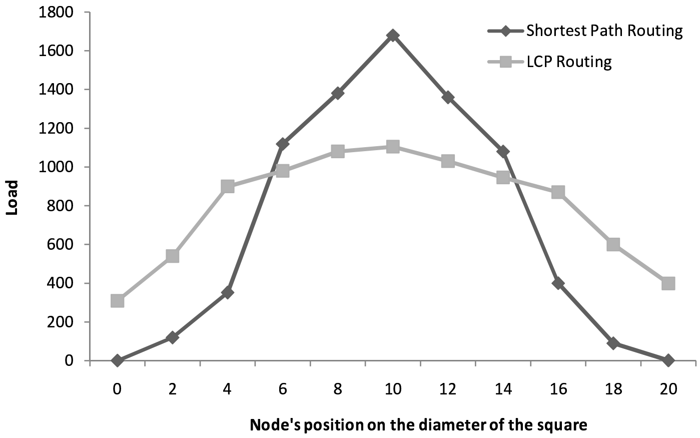

Fig. 3. Routing along shortest path and LCPs. The network is a square 20×20. communication range is equal to 5.

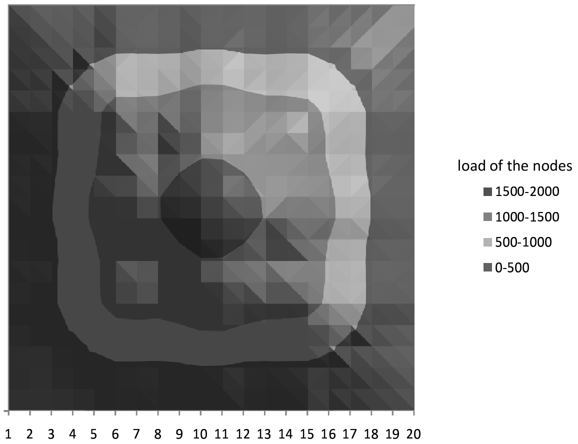

Fig. 4. The flat diagram of 20×20 network. Routing is along shortest paths.

IV. SIMULATION RESULTS

In this section results of the proposed method for balancing the load is presented. The nodes in the wireless network are located on a uniform grid. All nodes have same communication range (radius of visibility). Each node acts as the source node and sends one packet to other nodes in the network. The networks have approximately 500 nodes. This is very close to the real world dimensions [4]. Various values for communication range effects the results. Thus, the results for different amounts of communication range are presented.

Fig. 3 shows the results of routing along shortest paths and LCPs. The network is a square 20×20 with 400 nodes which are uniformly deployed on the grid. Also communication range is equal to 5. The decrease in the maximum load is about 35% using the proposed method. Fig. 4 and Fig. 5 show the flat diagram of this network using shortest path and LCP. According to these figures, the load of all nodes is approximately equal, with a small decrease near the edge. Considering the whole network, the edges of the network does not have significant effect in the performance of the method.

TABLE I

PSEUDO CODE FOR FINDING THE PROPER COSTS

```
Initialize cost vector $c$, $\forall\ i \in N : c(i) = default\_cost$
**while** $\forall\ i, j \in N : L(i) \simeq L(j)$
        calculate LCPs between every pair of nodes using Dijkstra's algorithm
        $\forall\ i \in N$ calculate $L(i)$
        $average\_load \leftarrow \frac{\sum_{i \in N} L(i)}{\|N\|}$
        **for** all nodes $i \in N$
            **if** $L(i) > average\_load$
                $c(i) \leftarrow c(i) + 1$
            **else**
                $c(i) \leftarrow c(i) - 1$
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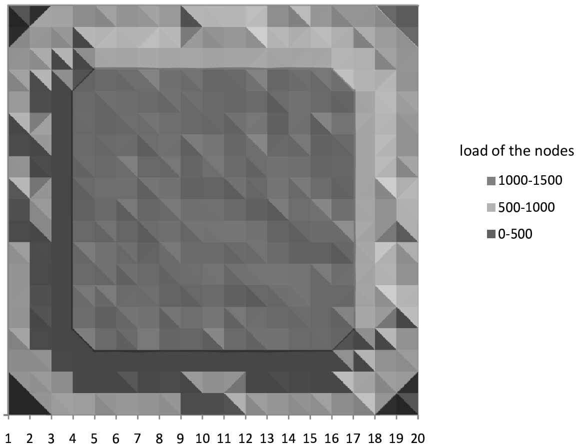

Fig. 5. The flat diagram of 20×20 network. Routing is along LCPs.

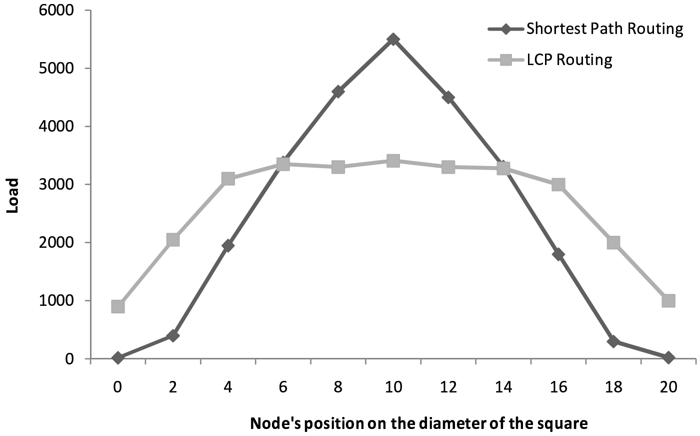

Fig. 6. Routing along shortest path and LCPs. The network is a square 20×20. communication range is equal to 5.

Fig. 6 shows the results of routing along shortest paths and LCPs. The only difference with Fig. 3 is that the communication range is equal to 2 and the decrease in the maximum load is about 38%. This decrease is more than the previous case. The reason is when the communication range decreases, the number of hops in the paths increase, the total load of the nodes increase and as a result, the chance of balancing the load increases.

V. RELATED WORK

Pham and Perreau [1] consider the higher loads of nodes near the center of a dense disc and also derive a formula of load probability for shortest path routing. Their formula only consider the disc shaped networks. Also they leave the transmission range parameter in their calculations. They propose the use of multiple paths to balance the loads and decrease the amount of traffic near the center of the network and analytically evaluate the approach. But, another work shows that the use of multiple paths does not obtain good results unless a very large number of paths are used for multipath routing [2].

The approach of routing to a random point has been proposed for a grid network but it has some overhead for computing the paths [8]. Baek and Veciana [9] used multiple paths for load balancing in wireless networks using theoretical approach. They focus on a particular communication between fixed endpoints. A routing algorithm for balancing the load of very narrow wireless networks was proposed in [10].

Dousse et al. present the impact of interference on the connectivity of large wireless networks in an infinite area [11]. Also they assume that the behavior of each node is independent of the other nodes. Using their model, they define the stochastic properties for the existence of links and present the existence of a giant component, which is related to the network connectivity. The authors of [12] present a model of a dense wireless network in order to achieve a better signal-to-noise ratio. They assume cooperative relaying, where several nodes transmit the same packet simultaneously.

MAP is a routing plan that has a balancing side-effect and is applicable on arbitrary topologies [13]. Also, for a network with disc topology, MAP routes the packets on the radius of source.

The authors of [4] addressed the problem of load balancing traffic in wireless networks to increase energy usage fairness and reduce congestion. They gave a formal description of the load probability for a disc network. As other load balancing algorithms, their idea is to route on curved paths rather than the shortest paths. They presented a theoretical approach based on geometric optics for finding and routing on the optimal paths.

Also, they developed Curveball Routing, a practical approach, which routes on virtual coordinates gained by projecting the network on a sphere. Their model is not applicable on networks with arbitrary topologies.

The authors of [3] present a model for balancing the load in dense wireless networks with disc topology and use the formula presented in [14] for the load probability. They theoretically analyze routing on inner and outer radii and present a randomized choice between shortest path routing and routing on the inner/outer radii to balance the load. Their approach is very limited because it is only applicable on dense wireless networks with disc topology. Our approach is independent of the topology of the network and is applicable on dispersed networks.

VI. CONCLUSION

In this paper, the problem of load balancing in wireless networks is addressed. We proposed a method, inspired by game theory, to balance the load of the nodes. We assume that each node incurs a cost for carrying the packets in the network. Also, source nodes prefer path with lowest costs. These paths are called lowest cost paths (LCP). By assigning higher costs to nodes which are located near the center of the network (regions with high amounts of traffic), the load of these nodes are decreased. Thus, an approximation algorithm for finding these costs is proposed. Also, because there is not any assumption about the shape and topology of the network, the proposed method is applicable on the wireless networks with arbitrary topologies. Our results suggest that this method successfully balances the load of nodes in wireless networks.

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