

Multi-Commodity Flow, Multiple Paths Load Balanced Routing in Ad-hoc Networks

Christine Safwat Wadie, Mohamed Ehsan Ashour

Networks Department, German University in Cairo, Egypt

christine.wadie@guc.edu.eg, mohamed.ashour@guc.edu.eg

Abstract— An Ad Hoc Network is an infrastructure-less network. Data exchange is supported by multi-hop routing between the nodes on the network. Most ad hoc routing schemes are based on shortest path metric or least hop count. These approaches result in using the same path for several commodities. Load balanced routing is one of the approaches that can be used to distribute traffic load over different network nodes hence decreasing the overall network delay. Balancing load among the network distributes the power consumption per node, increasing the network life time by avoiding the failure of a specific node. Such features work out on enhancing the network quality of service. However, the shared medium between the wireless nodes causes interference at the MAC layer which poses a major challenge to load balancing. This paper proposes the use of a multi-commodity flow, multiple paths load balanced routing scheme. The proposed scheme uses a new path length metric that is indicative of the interference seen by nodes across this path. The method requires very little storage capabilities which does not consume much power, in addition the scheme reduces signal forwarding since it mostly depends on node-aware data. Results show that the approach is capable of balancing the network load and that network delay drops significantly compared to existing routing schemes.

Keywords— Routing, Load balancing, Multiple Paths, Multi-Commodity, Ad-hoc, Flow Deviation

I. INTRODUCTION

Wireless ad-hoc network applications are becoming more popular nowadays. In situations where it is not possible to create a network through building an infrastructure, ad-hoc networks are a suitable solution. Ad-hoc networks are useful in many application environments, some of these situations are; battlefield situations, mine site operations or disaster recovery areas. Ad-hoc applications are mostly delay-sensitive as they are end user applications. However ad-hoc networks have many characteristics that degrade the network performance such as limited bandwidth, variable capacity links, energy constraints and limited storage capabilities. The shared medium is subjected to multiple access, signal fading, signal interference and noise. These parameters strongly affect the efficiency of wireless communication. Therefore the development of quality of service routing and improvement of the overall network performance has become an essential issue. Many works have been proposed for routing in a wireless medium, some of which are using a power-aware

routing approach [1], some propose stability based routing schemes [2] and others work on load balanced routing approaches [3], [4], [5] and [6]. Power-aware routing aims to route data while preserving power by selecting paths with largest residual battery charge, whereas stability based routing select the routes that will live longer and expire last. Load balanced routing select the paths that would encounter minimum traffic load for transmission and minimum interference by neighbouring nodes. Load balanced routing aims on balancing the traffic load on a network by selecting the least congested routes. It minimizes the sum of traffic interferences of the intermediate sensor nodes that form the route which decreases the involvement of a node. Decreasing the involvement of the most congested nodes lowers the power consumption of such nodes hence contributing in balancing the power consumption over the network while resulting in lowest overall network delay performance. In reference [7], a simulation study between the three approaches, power-aware routing, stability-based routing and load balanced routing has been introduced. The study clearly proves that load balanced routing incur the least energy consumption per data packet, in addition to the lowest end-end delay.

II. LOAD BALANCED ROUTING IN AD-HOC NETWORKS

All routing techniques aim to route data with shortest path or least hop count. In low node mobility, traffic may concentrate on a few nodes, resulting in high overall network delay due to the traffic congestion at these specific nodes. Moreover, since some nodes are used for a long time, their battery power may rapidly be exhausted causing short lifetime of the network. For better network performance, nodes must be involved in least transmission and reception actions possible. Yet routing data through ad-hoc network must be performed by the nodes on the network. Mostly all routing approaches mentioned above do not take into consideration the interference effect caused by the shared medium, in addition that they require signal transfer or high data storage to process their proposed routing schemes. Meanwhile, ad-hoc networks' major

challenge is the variable link capacities caused by the shared medium. Furthermore, ad-hoc networks necessitate low data signalling, low storage requirements. In this paper, a load balanced routing solution approach is proposed. The routing scheme, aims on balancing the power consumption over the network while reducing the overall network delay. This is achieved by balancing the traffic load on a network through selecting the least congested routes for transmission. The algorithm minimizes the sum of traffic interferences of the intermediate nodes that form the route which decreases the involvement of each independent node, especially the most congested. Decreasing the involvement of the most loaded or congested nodes lowers the power consumption of such nodes hence contributing in balancing the power consumption over the network while resulting in lowest overall network delay performance. Furthermore, the method used requires very low storage capabilities, which is very much convenient to the ad-hoc characteristics, hence enhances the overall network quality of service performance. Results prove that the overall network delay performance outperforms existing routing schemes.

A. Multi-Commodity Network Flow Problem in Ad-Hoc Networks

Multi-commodity flow problems have been proposed to enhance the network performance as found in [8], yet it solves the problem using single path for each commodity. In this paper the multi-commodity flow problem has been solved using multiple paths for each commodity. A multi-commodity flow problem models a network with several commodities that are using the same underlying network. The commodities are differentiated by their origin-destination pairs. Most multi-commodity flow problems that have been proposed to enhance the network performance use single path for each commodity as found in. Multiple-paths routing has the potential of improving the throughput. In this paper MM-LBRA a routing scheme models a multi-commodity network flow problem which uses multiple paths to satisfy the traffic demand of each commodity. The basic idea of the MM-LBRA routing scheme is to enhance ad-hoc networks quality of service performance in terms of residual capacity, delay and network life time. This has been achieved by modelling the network flow as a multi-commodity shortest path problem. Load balanced routing technique is used for the paths selected as the shortest paths, in a way such that each demand from a specific source to a specific destination could be satisfied using one path or more than one path. This depends on the available paths on the network and the average paths residual capacity on the network. The traffic load of each demand is distributed among the paths selected for each demand or commodity.

A path length metric was proposed to represent the cost or length of the links while indicating the interference drawback effect which occurs due to the shared medium characteristic of wireless networks. The cost metric is used to find the shortest paths that satisfy all the network demands. Load balancing is applied to the paths selected as the shortest paths, in a way such that each demand from a specific source to a specific destination could be satisfied using one path or more than one

path. This depends on paths available in the network and the initial load distribution on the network. Each demand load is distributed among the number of paths available for each demand or commodity. The load balancing technique used is based on the concept of flow deviation (FD).

B. Flow Deviation Method (FD)

The flow deviation method found in [9] is a primal method that has been proposed for the message routing problem where it aims to minimize the overall delay on the network by balancing the load on the network paths. To deal with capacity constraints, the delay function F is replaced by

$$F = \frac{x_{i,j}}{c_{i,j} - x_{i,j}} \quad (1)$$

Where F is the delay function, $x_{i,j}$ is the load on the link i, j and $c_{i,j}$ is the capacity on the link. The message routing problem is written as; $\min f'(x)$. The method successively solves sub-problems to get a feasible path solution. The sub-problems are solved by computing shortest paths between each pair (i, j) and loading the required amount of flow onto the corresponding path. The link costs used when finding cheapest routes are the partial derivatives of the objective function. The entire method consists of the following steps;

- 1) Find a feasible total flow
- 2) Sub-problem, for each commodity d find a minimum first derivative length path between (i, j) (the first derivative are evaluated at the current solution) and let $y_{i,j}$ be the flow or load obtained by loading the corresponding amount r onto this path. Then update the total vector flow; $y = \sum_d y_d$ (Step length search), determine α .
- 3) Flow Deviation: $(1 - \alpha)x + \alpha y$.

In this work, the steps of the flow deviation method have been applied on wireless ad hoc multi-commodity flow for load balancing. To retrieve the complete routes taken by each commodity, all that is needed is to simply store the individual paths generated during the iterations. Since the optimal total link flows are the only quantity of interest then the implementation of the flow deviation method requires a small amount of storage, which is a characteristic that is essential for wireless ad-hoc networks and so taking use of this advantage allows solving very large network problems.

III. AD-HOC DELAY MINIMIZATION PROBLEM

Below is the proposed metric formulation starting by the definitions for the terms used for the formulation and ending by the worked out objective function. $x_{d,p}$ is the load of demand d on path p , H_d is the total load of demand d and Y_e is the actual traffic moving on link e . C_e is the maximum rate of link e while T_n is the time ratio of node n , the ratio of time in which node n cannot be involved in transmission or reception. The remaining capacity/maximum rate on link e is R_e and the delay at link e d_e . The time share of link e is expressed as τ_e and $\delta_{d,p,n}$ equals 1, if path p for demand d goes through link e whereas $\eta_{e,n}^{(T)}$ equals 1, if link e is

transmitted on from node n . As for the connectivity it is illustrated by $\omega_{n,m}$, where it equals 1, if node m is in range of node n . The average delay experienced by the whole network is F and the total load of all the network demands is X . Finally the cost or length of a link e is notated as l_e and that is the proposed metric.

The delay on a link e between any two nodes is defined as;

$$d_e = \frac{1}{R_e} \quad (2)$$

The delay experienced by an arc or link between two nodes i and j in a multi-commodity flow problem is defined in [10] as;

$$\sum_{(i,j) \in A} \frac{x_{i,j}}{u_{i,j} - x_{i,j}} \quad (3)$$

Where $x_{i,j}$ is the flow on a link between nodes i and j , whereas $u_{i,j}$ is the fixed capacity of an arc or link. Therefore it calculates the remaining capacity of the link by subtracting the load or flow passing through the link from the total capacity of the link. This is valid in wired networks where the flow on a link is simply the amount of traffic being transmitted on the link. However in wireless networks link flows are not a definite value that can be obtained, this problem arises from the shared medium characteristic of wireless ad-hoc networks. All nodes on a network share the same medium to transmit and receive through. So the amount of traffic travelling on a wireless link is in function of not only the transmission and reception actions of the two nodes connecting this link but also all other actions taking place by any other node that are within the same transmission range.

T_n is the ratio of time where node n cannot be involved in transmission or reception actions and $1 - T_n$ is the ratio of time when node n is free. Same applies for node q , where the ratio of time where node q cannot be involved in transmission or reception actions is T_q and so $1 - T_q$ is the ratio of time when node q is free. Consequently the residual capacity is considered as $1 - T_n$ and $1 - T_q$ multiplied by the maximum rate C_e of link e . This is applied because of the fact that the medium is shared and since it is shared then the maximum rate availability is affected by both time ratios. Therefore, the remaining capacity or maximum rate remaining on link e between node n and node q is defined as;

$$R_e = C_e * (1 - T_n) \quad (4)$$

Hence the delay is termed as;

$$d_e = \frac{1}{C_e(1 - T_n)} \quad (5)$$

Of course this does not give an accurate value for the delay but rather a proportional one since it is well known that finding the exact accurate calculation of the delay in a wireless network is not an easy task. However, the aim of this paper is to reduce the delay hence using a proportional value to the delay and decreasing it causes no problem as the technique could still be applied on accurate delay values and

decreasing those values too. The time share of a link e is the actual traffic moving on link e over the capacity of the link;

$$\tau_e = \frac{Y_e}{C_e} \quad (6)$$

Y_e is calculated as the summation of the loads transferred on each link used by each path of all demands;

$$Y_e = \sum_d \sum_p x_{d,p} * \delta_{d,p,e} \quad (7)$$

The total demand X on the network is obtained by summing up the total loads required by each demand;

$$X = \sum_d H_d \quad (8)$$

The time ratio of node n is calculated as;

$$T_n = \sum_e \tau_e * \eta_{e,n}^T + \sum_m \sum_i \tau_i * \eta_{i,m}^T * \omega_{n,m} \quad (9)$$

Time ratio of the node is the ratio of time that node n cannot be involved in any transmission or reception activities. Where the first term represents the effect of transmission actions and the second term represents the effect of reception actions. Therefore the interference effect must be taken into consideration. So the transmission and reception actions that occur within the range of node n are calculated as they have great impact on how the time ratio of the node will be determined. The effect of transmission is calculated by adding the total time ratios of all links that node n uses for its transmissions. As for the reception effect, it is obtained by summing up the total time ratios of all the links that any node m is using for transmission, given that node m is within the transmission range of node n . The average delay experienced by the whole network is expressed as;

$$F = \sum_d \sum_p \frac{x_{d,p}}{X} \sum_e \delta_{d,p,e} * d_e \quad (10)$$

A. Flow Deviation in Wireless Ad-hoc Networks

According to step 2 in the flow deviation method, a minimum first derivative length path between (i, j) should be found and used as the cost or length of the links. So the metric proposal has been achieved as illustrated in Figure 1: Proposed Metric.

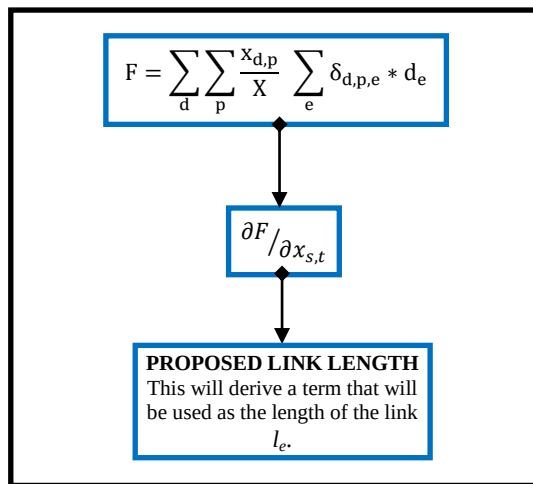


Figure 1: Proposed Metric

B. Simulation Study

Flow deviation method was applied to the wireless sensor network simulation using the proposed length path metric and the simulation was modelled using matlab. Steps of the flow deviation method were applied by finding feasible flows as an initial step. Shortest paths were derived for all demands using Dijkstra's Shortest Path Algorithm where the paths are selected according to shortest distance. A path is retrieved for each demand and the load of the related demand is added to all links of the path. The overall network delay is calculated and that is the value that the model works on improving in order to enhance the overall network performance. An iterative method starts and the new proposed length l_e is figured for all links found on the network. The master problem is separated to sub-problems of shortest paths commodities. Given the new cost or length (l_e) of the links and the new weights on the network, shortest paths are computed again for each demand. A new path may be found for a demand or the old path is selected again if it is found to be the shortest still. This set of shortest paths is referred to as the new paths, whereas the set of shortest paths computed by Dijkstra's is referred to as the old paths. Formerly, a search process starts to find a value for α by a trial and error procedure. After the search process, the value of α that produces the least delay is nominated as the selected α and is considered as the optimal solution for the current iteration. The set of old and new paths are stored with the value of the selected α and the load on these paths is distributed according to the nominated α . The overall network delay due to this load balance is now considered as the value considered for comparison in the next iteration. The set of stored paths is considered as the old paths for the next iteration and the whole process is repeated iteratively until the value of the overall network delay cannot be further improved. The final set of path deduced is considered to be

the shortest selected paths that satisfy the network demands such that the overall network delay is reduced and so enhancing the overall network performance.

C. Simulation Results

A connection is considered to exist between two nodes if the power received is greater than a certain power threshold. The capacity $c_{i,j}$ of a link connecting two node i and j is assigned a maximum rate according to the distance between the two nodes. It is assumed that a worst case scenario exists such that all interferes within a range are transmitting at the same time. It is also assumed that initially the demands are known to the network with the source node, destination node and total amount of load required to be transferred across the network for each demand. The model has been tested on uniformly ordered networks and randomly ordered networks and the results are demonstrated below. The figure shows a uniform network of 25 nodes with 4 network demands. Figure 2 illustrates the shortest paths chosen by Dijkstra's and figure 3 shows the final selected paths by the proposed model. The figures demonstrate how the proposed routing scheme attempts to minimize the sum of traffic interferences of the sensor nodes in a path; where it routes data through the nodes that are least congested. It is made clear in the finally selected shortest paths how the paths chosen move away from the area that shows an indication to interference. Results show that the overall delay drops from 0.0399ms to 0.0306ms which indicates a 23.3% drop at = 0.66 .

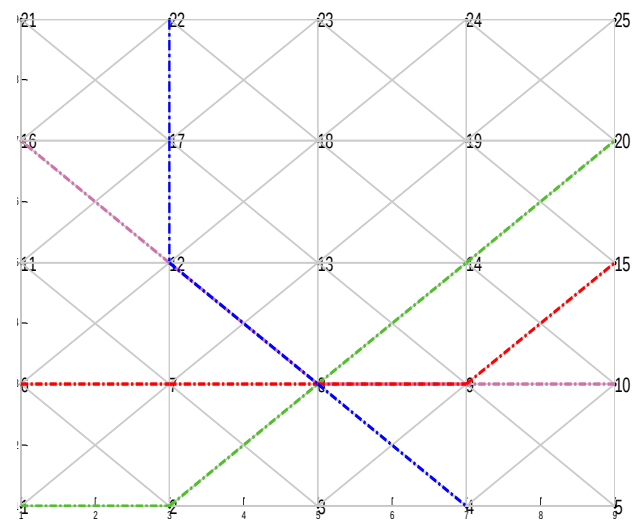


Figure 2: Initial Shortest Paths

In the above network model, there exists four network demands as follows; node 1 transmitting to node 20, node 6 transmitting to node 15, node 10 transmitting to node 16 and node 22 transmitting to node 4. The paths shown on the figure are the paths selected by Dijkstra's shortest path algorithm. Each demand or commodity is transferred using one single path and the intermediate nodes are used repeatedly in more

than one path. The illustration shows clearly that congestion is very high at the part of the network where the intermediate nodes lie. After applying the proposed routing scheme, the load is balanced in a way that reduces the use of the same intermediate nodes or the most congested nodes. Figure 3 clarifies that even though the same nodes might be used in more than one commodity yet less traffic travels through the nodes since the load is balanced by a factor α . Furthermore, multiple paths are selected to satisfy each commodity.

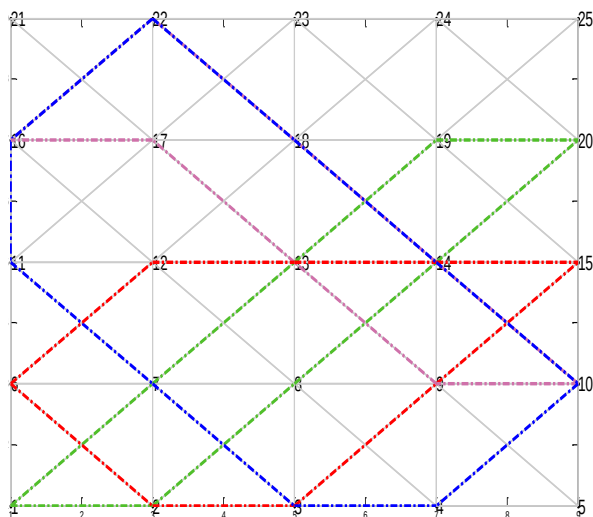


Figure 3: Final Selected Shortest Paths

TABLE 1. PERCENTAGE DROP IN THE OVERALL NETWORK DELAY

	Uniform Network		Non-Uniform Network	
Number of Nodes	25	50	25	50
High Network Demand (20 Tx)	21.4%	16.7%	13.9%	7%
Low Network Demand (10 Tx)	23.3%	21.3%	19.9%	10%
High Network Connectivity	6.5%	8.8%	14.8%	10%
Low Network Connectivity	6.3%	11.5%	26.5%	15%
High Network Load (100 GB)	21.4%	35.9%	30.3%	39.4%
Low Network Load (50 GB)	4.8%	9.3%	23.4%	26%

Although the above results show a comparison to Dijkstra's shortest path algorithm yet it was not the only algorithm modelled. The minimum hop count algorithm scheme and the minimum delay algorithm scheme have also been modelled. Promising results were produced from the comparison

between the proposed scheme and each of the mentioned routing schemes.

IV. CONCLUSION

In this paper a multi-commodity flow, multiple paths load balanced routing scheme has been proposed. The proposed approach derives a path length metric for routing. The metric calculates the length of a wireless link in a way that presents an indication of the neighbour interference experienced by a network node. Additionally, the flow deviation method that is used in wired networks has been applied to wireless ad-hoc networks. Feasible routes were determined and the new metric was measured and used to find shortest paths iteratively where the load is balanced by shifting some load from old paths to new paths. The flow on the network is shifted from the non-shortest paths in equal proportions. Different network topologies have been simulated and the overall network delay was calculated. Results prove that the routing scheme enhances quality of service routing in wireless ad-hoc networks. This has been measured by the overall network delay; in addition that it requires low network signalling and extremely low storage capabilities. Moreover the paths selected by the routing scheme decreases the involvement of each node in accordance to the proposed metric which helps in consuming less power. The enhanced specifications deduced by the results, contribute to developing the overall wireless ad-hoc network quality of service performance.

REFERENCES

- [1] Toh C-K, "Maximum battery life routing to support ubiquitous mobile computing in wireless ad hoc networks," *IEEE Communications Magazine*, vol. 39, no. 6, pp. 138-147, June 2001..
- [2] J Su W., Lee S-J., and Gerla M., ""Mobility prediction and routing in ad hoc wireless networks,"" *International Journal of Network Management*, vol. 11, no. 1, pp. 3-30, 2001.
- [3] Hassanein H. and Zhou A., "Routing with load balancing in wireless ad hoc networks," in *Proceedings of the 4th ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, Ontario, 2001, pp. 89-96.
- [4] Xiangquan Zheng, Wei Guo, Renting Liu, and Yongchun Tian, "A New Dynamic Load-aware Based Load-balanced Routing for Ad Hoc Networks," in *Communications, Circuits and Systems, ICCAS 2004*, Chengdu, 27-29 June 2004, pp. 407-411 Vol.1.
- [5] Omar Al-Jarrah and Musab Salem Al-Hadrosi, "Load Balanced Ad Hoc Routing Protocol," in *Mobile Computing and Wireless Communication International Conference, 2006. MCWC 2006*, 17-20 Sept. 2006, pp. 20-26.
- [6] Abdulrahman H. Altalhi and Golden G. Richard, III, "Load-balanced routing through virtual paths: highly adaptive and efficient routing scheme for ad hoc wireless networks," in *Performance, Computing, and Communications, 2004 IEEE International Conference*, New Orleans, 2004, pp. 407-413.
- [7] Natarajan Meghanathan and Leslie C. Milton, "A Simulation Based Performance Comparison Study os Stability-Based Routing, Power-Aware Routing and Load Balancing On-Demand Routing Protocols for Mobile Ad Hoc networks," in *Wireless On-Demand Network Systems and Services, Sixth International Conference., WONS, 2009*, pp. 3-10.
- [8] Vinay Kolar and Abu-Ghazaleh Nael B., "A Multi-Commodity Flow Approach for Globally Aware Routing in Multi-Hop Wireless Networks," in *Proceedings of the Fourth Annual IEEE International*

- Conference on Pervasive Computing and Communications, Binghamton, 2006.
- [9] A. Ouorou, P. Mahey, and J-Ph Vial, *Management Science*.: INFORMS, 2000.
- [10] Ravindra K. Ahuja, Thomas L. Magnanti, and James B. Orlin, *Network Flows (Theory, Algorithms and Applications)*, Pete Janzow and Merrill Peterson, Eds. Upper Saddle River, New Jersey, United States of America: Prentice-Hall, 1993.



Christine Safwat Wadie, was born on 16 March 1987 in Cairo, Egypt Had obtained Bachelor degree in the field of Information Engineering and Technology from the German University in Cairo. Currently working on Master Science Degree in the field of Routing in Ad-hoc Networks. Teaching Assistant in the German University in Cairo since 2008. Certified as a CCNA CISCO Instructor as of May 2012.

Interned at Atlantic Industries Coca-Cola Egypt in 2007. Interned in Universe Network Planning and Cabling in 2006. Interned at Orascom Construction in the IT Department in 2005.