Improving the Lifetime of Wireless Ad Hoc Networks Using Power Aware Routing

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ABSTRACT- **This paper discusses the energy saving control problem in ad hoc wireless networks. The problem can be formulated as a number of randomly placed nodes in a plane with a given area and a required traffic load constrained by end to end delay bounds. We try to find an optimized routing path that can meet the Quality of Service requirements and minimizing the total consumed power of nodes. In addition to that, the network life time must be maximized by considering fairness among power consumptions of nodes indicated by the variance between nodes consumed power levels. An optimal algorithm has been proposed to solve the problem using "integer linear programming" along with a set of power and energy constrains. Our proposed scheme chooses the shortest hops if the battery energy of nodes are sufficient. When the battery capacity of some node falls beyond certain threshold, routing through these nodes must be avoided and therefore the time till the first node power is drained will be extended.**

Keywords: ***ad hoc wireless networks lifetime, cooperative communications, Power Aware Routing, Variance of node power levels***

I. INTRODUCTION

An ad hoc wireless network is a type of wireless networks that does not have centralized infrastructure to support communication among nodes. In multiple hop ad hoc wireless networks, communication between two nodes requires the relay of messages by intermediate nodes if they are not direct neighbors. Each node acts as a router, as well as a transmitter and a receiver. It is a special type of wireless network with an association of nodes that cooperate. Thus, in this scenario of cooperation, each node tries to help for the benefit of the entire network not only for its own benefit. In the same time, it should also preserve some resources for its own use. For example, a node could reserve up to 60% of its transmission power to help as a relay node, while keeping 40% just for its own communication needs. This implies that as the power reserved for the network benefit has been consumed, the node then 'hides' itself, and refuses to act as a possible relay node. In this paper we try to find this optimum value (threshold) for the node reserved power to stop acting as a relay, meanwhile maximizing the network lifetime. Optimizing a group of multiple parameters such as energy consumption, packet-error-rate, routing overhead, bandwidth, route repair etc, must be the aim of routing protocols rather than only minimizing the number of hops[1][2]. Developing routing protocols for MANETs are under extensive research efforts during the past years, taking into consideration the energy efficiency which is the most crucial design criteria for MANETs [3]. Since nodes have limited battery capacity, if a node runs out of battery, this will affect its ability to route the traffic of other nodes and thus affecting negatively the overall network lifetime. For protocols that maximize the overall network lifetime, the main focus is to distribute the energy consumption among all nodes in a balanced manner. If the route with maximal energy saving is always chosen for delivery, the subset of nodes along this route will be over utilized and therefore drained in a short period of time which may lead to network partitioning. In order to use the energy of nodes in a fairer manner, the traffic must be routed through the nodes that have enough remaining energy, not only by selecting routes simply based on energy consumed. Different approaches were presented to fulfill this target. "Load distribution" and "transmission power control" [4][5] are two approaches to minimize the communication of energy of the network nodes. The load distribution protocol avoids the choice of exhausted nodes at the route selection phase, thus balances the use of energy among nodes and maximizing the network lifetime. In transmission power control approach, there is a balance between the choice of a high transmission power that lead to increase in the range of signal transmission thus reducing the number of hops and lower power levels that reduces the interference on the expense of network connectivity. Hence it is important for the routing protocol to choose a path that leads to an acceptable QoS, meanwhile maximizing the network lifetime [6]. The metrics of power/Energy efficient routing protocols that had been introduced as an alternative of the shortest path routing can be stated as [7]

- The Energy consumed per packet.
- Maximizing the network lifetime.
- The Variance between nodes power levels.
- The transmission cost per packet.

The energy consumed per packet can be used to minimize the total consumed energy for a packet to reach the destination by selecting the minimum power route where each node knows the energy cost required for transmitting over each link and the ones with minimum energy along all the route is chosen to minimizes the sum of the total energy consumed. Nevertheless, the routing protocols using this metrics may lead to a large variance between nodes power consumption levels and unequal power utilization by the nodes in a route. This can be explained as follows. When some particular nodes are overloaded by routing the heavy traffic of other nodes, their battery consumption will be high, thus leading to an early

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exhaustion and get drained faster than the other nodes in the network. This will disturb the whole ad hoc network leading to its early disconnection. This indicates that maximizing the lifetime of the overall network must be of a considerable importance. Routing protocols must try to choose the path that balances the energy consumption of all the nodes and choose the route that leads to maximum lifetime of the network as a whole. Since the future traffic demands is difficult be anticipated in prior, then "Minimizing variance of nodes power levels" metric is of equal importance. This can be explained as trying to balance the energy consumption of nodes fairly and no node is to be used unfairly more the other network nodes. The variance between the nodes consumed power level can be used as an indication of the fair usage of these nodes. The "transmission Cost per packet" metric takes the remaining battery level and the cost of a new transmission, in terms of the required transmission energy, as a guide for selecting the routing path for maximum lifetime. Power aware Localized Routing (PLR) [6] is an energy aware routing protocol that considers that each node knows exactly the location of all the other nodes in the network as well as its destination. Proposals that are considering load distribution approach can be found in [7, 8]. Localized Energy Aware Routing (LEAR) Protocol [7] is one protocol that introduces a change in the sequence of route discovery phase for balancing energy consumption using Dynamic Source Routing (DSR). Conditional Max-Min Battery Capacity Routing (CMMBCR) Protocol [8] maximizes the lifetime of each node and uses the battery fairly. In this paper, we run the QoS routing algorithm [9] such that the maximum transmitting power of nodes is minimized. The QoS of our concern are traffic demands, maximum delay bounds between end-nodes, and fairness among nodes consumed energy levels. The main objective is fairness among consumed power distribution of nodes. In other words, "minimum variance between nodes power levels". We are using this method as one of our measures to ensure fairness among network nodes, and then we try to find an optimum threshold on the exhausted nodes power level to eliminate them from routing process meanwhile enabling them to send and receive their own traffic, thus the network lifetime can be prolonged. We assume that transmission power is large enough such that receiving power is considered relatively negligible [10][11], thus, we only focus on the transmission power (energy) of all nodes. We draw the attention to the tradeoff between two important factors that affect the lifetime of the network. First, if a sending node wants to transmit its traffic, it has two choices, either to relay its traffic through some center nodes using many hops, this will give better lifetime for those sending nodes in terms of using shorter hops thus less power, but in this case, the battery of center relay node will drain quickly. The second choice is that if the sending node transmits directly to the destination over longer hops then its power content will decay fast while relaxing the center nodes. If the goal of the routing protocol is only to discover a minimum total power (energy) route, the nodes in the network may tend to have widely different energy consumption profiles, resulting in early death of some nodes. Fig.1 illustrates the shortcoming of minimum power routing. We suppose node 6 will be selected as the relay node for the packets from 0-3, 1-4, 2-5. As a result, node 6 will exhaust its battery faster than the other nodes and will be the first to be drained. If a source node at the edge of the network transmits directly to the destination as for example 1-4, its energy will decay fast and the overall lifetime will be reduced. Note that most of the power-aware routing protocols only consider node transmission power. To maximize the lifetime of an ad-hoc network, the overall consumed power of each route must be minimized, meanwhile the total consumed power must be evenly distributed among nodes. However, these two objectives cannot be satisfied at the same time by metrics considering power or battery reserve alone. There is a tradeoff between the two. Our goal is to find a balanced scheme that can meet these two considerations together with end-users QoS requirements and has minimum energy consumption with maximum lifetime.

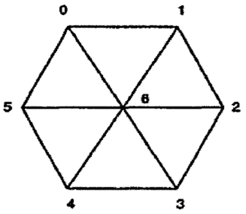

Figure 1. Shortcoming of minimum power routing

II. SYSTEM MODEL

In this work, We consider the transmitted power is the minimum power that can be used to guarantee network connection given as: $P_{ij} = p_{sj}\,(d_{ij}^{\alpha})$, where P_{ij} is the transmitting power used by the node (i) to reach destination (j), p_{sj} is the destination receiver (j) sensitivity, d_{ij} is the distance between node (i) and node (j), and (α) is the path loss exponent ranging from 2 to 4. The cost of energy for source node (i) to reach destination (j) can be given as: $E_{ij} = P_{ij}\,T_p$, where T_p is the time of transmitting the required traffic request. The network is described by G = (V, W), where V is the group of (n) nodes and W is a group of bi directional edges. Let P(i) denote transmitting power of node(i). We assume that each node can use a different transmission power level, until it reaches its maximum reserved power capacity P_{max}. That is, $0 \leq \mathrm{P(i)} \leq \mathrm{P}_{\max}$ for $0 \leq \mathrm{i} \leq \mathrm{n}$. Depending on the transmission power of nodes and their distances, there will be connectivity between them. An edge (i,j) $\in$ W iff $\mathrm{P}\,(i) \geq p_{sj}\,(d_{ij}^{\alpha})$. Let λ_{sd} and Δ_{sd} denote the traffic demand and the maximum allowed hop-count for node pair source (s) to destination (d) respectively. Let $\mathrm{E_{total}} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{E}(i)$. where $\mathrm{E_{total}}$ is the total energy consumed by all nodes and $\mathrm{E}(i)$ is the individual node required energy to forward a traffic demand. The energy control problem of our concern can be formally defined as: given a node set V with their locations, traffic demand λ_{sd} and hop count Δ_{sd} for node pair (s, d), find transmitting energy E(i) for $1 \leq i \leq n$, such that all the traffic demands can be routed within the hop-count bound, the given bandwidth and the total consumed power is minimized while achieving maximum lifetime. We assume that each node can transmit signals to other nodes in a collision free manner. Thus, we do not consider signal interference. There are many MAC (medium access control) layer protocols

[12,13,14] or code assignment protocols that have been proposed to avoid (or reduce) signal interference in radio transmissions

III. CONTROL PARAMETERS

Given:

- *V*, set of *n* nodes and their locations.
- *B*, the bandwidth capacity of each node.
- $\lambda_{s,d}$, traffic demands for each node pair(*s*, *d*).
- $\Delta_{s,d}$, max. Hop-count between (*s*, *d*).
- E_{max}, maximum energy capacity of each node.

Variables:

- Z_{ij} are Boolean variables, Z_{ij} =1 if there is a link from node *i* to node *j*, else, Z_{ij} = 0.
- Z_{ij}^{sd} are Boolean variables,Z_{ij}^{sd} =1 if there is a route from s to *d* going through link (*i*, *j*), else Z_{ij}^{sd} = 0.
- E_{total} , the total transmission energy of all nodes.

Optimize:

Minimize the total transmitting energy of nodes.

$$Min \quad E_{total} = \sum_{i=1}^{n} E(i) \tag{1}$$

Constraints:

- *Topology constraints:*

$$Z_{i,j} = Z_{j,i} \qquad \forall\, i,j \in V \tag{2}$$

This constraint ensures that each edge corresponds to two directed links.

$$Z_{i,j} \le Z_{i,j'} \;\; if \;\; d_{i,j'} \le d_{i,j} \qquad \forall\, i,j,j' \in V \tag{3}$$

Constraint (3) ensures that nodes have broadcast ability. This feature can be represented by the links in the network as: for node (*i*), if there is a link to *j* (*i.e.*, *Zi,j* = 1), then there must be a link to any node *j*' (*i.e.*, *Zi,j'* = 1) when *di,j'≤ di,j*.

- *Transmitting Energy Constraints:*

$$\mathrm{E}_{\text{total consumed}}(\mathrm{i}) \le \;\mathrm{E}_{\max} \qquad \forall\, \mathrm{i} < j\,, i\,, j \in \mathrm{V} \tag{4}$$

It means that the total consumed energy for each node is always less than the total node energy capacity.

$$\mathrm{P}_{\text{reserved}}(\mathrm{i}) \ge \; p_{sj}\left(\mathrm{d}_{\mathrm{i,j}}^{\propto}\right) \forall\, \mathrm{i} < j\,, i\,, j \in \mathrm{V} \tag{5}$$

It ensures that the reserved node power is enough to cover the required transmission.

- *Delay Constraints.*

$$\sum\nolimits_{\mathrm{i,j}} \; \mathrm{Z}_{\mathrm{i,j}}^{\mathrm{s,d}} \le \Delta_{\mathrm{s,d}} \qquad \forall(\mathrm{s,d}) \tag{6}$$

This constraint ensures that the hop-count for each node-pair does not exceed the pre-specified bound.

- *Bandwidth Constraints*

$$\sum\nolimits_{(s,d)} \sum\nolimits_{j} Z_{i,j}^{s,d} \;\lambda_{s,d} + \sum\nolimits_{(s,d)} \sum\nolimits_{j} Z_{j,i}^{s,d} \;\lambda_{s,d} \le B \;\forall \in V \tag{7}$$

This makes sure that the total transmission and reception at a node do not exceed the bandwidth of this node. The first term at the right hand side of inequality (7) represents all the transmitted traffic at node (*i*) and the second term represents all the received traffic. Although this constraint does prevent the case of transmission and reception during the same time, it can be applied to the usual case where a node cannot transmit and receive simultaneously as it is equipped with only one transceiver.

- *Route (flow) Constraints*

$$\sum\nolimits_{j} Z_{i,j}^{s,d} - \sum\nolimits_{j} Z_{j,i}^{s,d} = \begin{cases} 1 & if \quad S = i \\ -1 & if \quad d = i \;\; \forall\; i \in V \\ 0 & otherwise \end{cases} \tag{8}$$

Constraint (8) is for flow conservation, $Z_{i,j}^{s,d}$ is either 0 or 1, representing either the entire traffic of (*s, d*) go through link (*i, j*) or none does. In other words, the traffic entering a node is equal to the traffic leaving the same node.

- *Route validity.*

$$\mathrm{Z}_{\mathrm{i,j}}^{\mathrm{s,d}} \le \mathrm{Z}_{\mathrm{i,j}} \qquad \forall\, \mathrm{i,j} \in \mathrm{V} \tag{9}$$

Constraint (9) ensures that the route is valid between each node-pair, stating that traffic is flowing directly from node *i* to node *j* only when there is a link between them.

- *Binary Constraint*

$$Z_{i,j}^{s,d} = 0, or\ 1, Z_{i,j} = 0, or\ 1 \quad \forall\, i,j \in V, (s,d) \tag{10}$$

The problem of QoS power control has now been formulated as an *Integer Linear programming problem* (ILP) (1)-(10), which is NP-hard in general. In this work Matlab is used to solve this problem by simulation. The main objective here is fairness among nodes consumed power distribution. The idea is formulated in two steps: **First:** all nodes are allowed to transmit and receive freely beside that they participate in routing the traffic from other nodes. **Second:** if the node consumed energy reaches a specific threshold (say:50%,60%,…..90%) of the total available energy for that node (E_{max}) then it will broadcast to all other nodes that it will hide itself and refuse to act as a possible relay node, but will continue to send or receive its own traffic. This can achieve a tradeoff between the problems described in Fig.1.

IV. SIMULATION RESULTS AND ANALYSIS

Simulations are conducted in a 500m×500m two dimensional free-space region. The assumed number of nodes is set to be 20. The coordinates of the nodes are uniformly and randomly distributed. All nodes share the same bandwidth B_T = 11Mbps. The set of requests R = {(*s*, *d*, $\lambda_{s,d}$, $\Delta_{s,d}$)} are generated by using the Poisson function (i.e., the requests originating from a node follow the Poisson distribution). For each node, we use the random Poisson function with the mean value λ= 1 to generate a number *k*, which is the number of requests originating from this node. For the *k* requests, the receiving nodes are randomly chosen from the other nodes. Traffic demand $\lambda_{s,d}$ for a pair of nodes (*s*, *d*) is assigned by a random function of a normal distribution with variance equal to 0.5 λ_m , where λ_m is the mean value of the normal distribution function. i.e., λ_m is the average bandwidth demand per request. We use different traffic demands λ_m as a percentage of the node bandwidth. The maximum hop count $\Delta_{s,d}$ for all node pairs is set to (2n / 3). For each traffic demand λ_m, we randomly generate a number of requests for each node as seen in Table1. The sensitivity of the receiving node is set to -85dBm and adding an extra 12dBm to account for multipath fading and shadowing effect. The average number of requests that a node can support is considered as an indication of the lifetime for that node and for the entire network. We need to find the optimum threshold that maximizes the lifetime of the network. We define the network life time as the time taken for the first node to run out of battery. Since the performance of this scheme is a function of threshold, different threshold values are examined from 50% of E_{max} to E_{max}, where E_{max} represents the case of No-threshold applied, i.e. no protection margin is applied. The variance of node (energy) levels is illustrated in Fig.2.

Table 1. Rout path for traffic demand λ_m =10% of the node bandwidth (B).

Req #	λ_{sd} (kbps)	S	d	Routing Path
1	55.759	1	14	1-->6-->14
2	56.351	2	5	2-->8-->14-->5
3	55.494	3	7	3-->2-->8-->7
4	53.754	3	13	3-->13
5	52.196	4	20	4-->14-->7-->19-->20
6	50.916	5	11	5-->14-->8-->13-->11
7	59.738	5	19	5-->12-->10-->19
8	58.468	5	9	5-->14-->8-->2-->9
9	51.167	6	1	6-->1
11	50.753	6	7	6-->4-->14-->7
12	55.890	7	16	7-->12-->10-->19-->20-->16

It can be observed that the variance at E_{max} (No-threshold) has a larger value than at lower threshold values. At lower values of threshold, the nodes are protected from cooperation at an early stage before they drain their battery capacity, thus the variance between nodes consumed power levels is low, however for larger values of threshold, the nodes are protected from cooperation at later stages, thus some nodes are utilized more than the others, leading to a larger difference in the consumed power levels among different nodes, i.e. higher variance. In other words, as seen in Fig.3, at low threshold values, as most of the nodes reach their non-cooperative stage early, the probability of longer hops increases, thus increasing the power consumption of each node leading to a negative impact on the network lifetime. On the other hand, as the threshold value increases, the probability of selecting shorter hops increases, thus reducing the consumed power level of each node, but this happens at a later stage where the variance of power levels between nodes has already increased. Here we can see the tradeoff between these two goals arriving at an optimum threshold value of 80% of E_{max} for different values of traffic demands.

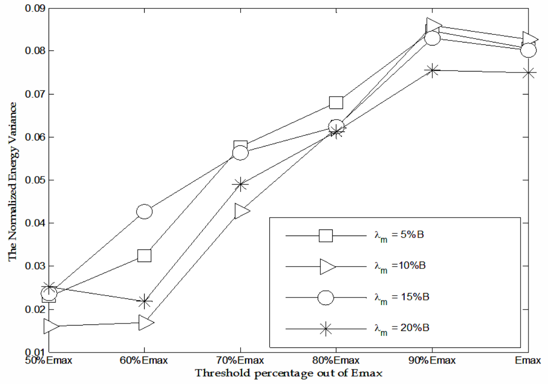

Figure 2. Normalized Energy variance vs. threshold

Note that higher values of the mean traffic demand (λ_m) requires more power and thus decreasing the lifetime of the network, this can be observed in Fig.4 where at different values of traffic demands, each threshold value is plotted. Increasing the threshold value leads to increase in the lifetime of the network until a threshold value of 80% of the total energy capacity of the node, i.e. the remaining energy is 20% before the node power is completely drained. While this value depends on the network size and topology requirements, these considerations can be used as a part of system and protection design.

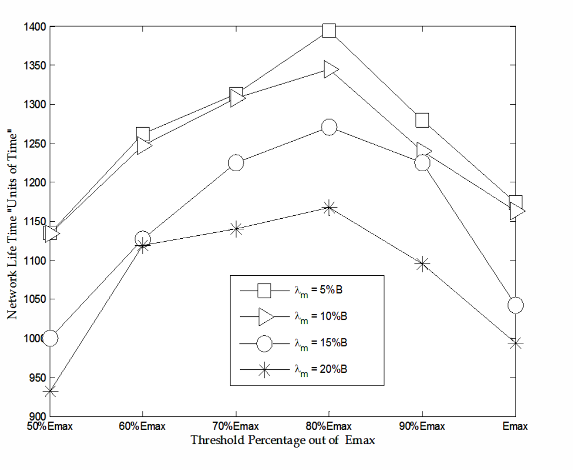

Figure 3. Network lifetime vs. threshold

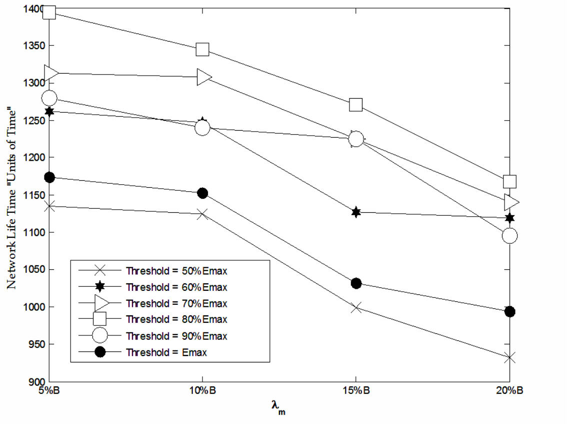

Figure 4. Network lifetime vs. traffic demand

REFERENCES

[1] S. Banerjee and A. Misra, "Minimum Energy Paths for Reliable Communication in Multi Hop Wireless Networks," Proc. MobiHoc, 2002.

[2] A. Khan, T. Suzuki, M. Kobayashi, and M. Morita, "Packet Size Based Routing for Route Stability in Mobile Ad-hoc Networks," Proc. IEEE Personal, Indoor and Mobile Radio Comm. (PIMRC), 2007.

[3] X.-Y. Li, Y. Wu, H. Chen, X.-W. Chu, Y. Wu, and Y. Qi,"Reliable and Energy Efficient Routing for Static Wireless Ad Hoc Networks with Unreliable Links, " IEEE Transactions on Parallel and Distributed Systems, Vol. 20, no. 10, pp. 1408-1421, Oct. 2009.

[4] S. Jayashree, B.S. Manoj, and C. Shiva Ram Murthy, "Energy Management in Ad Hoc Wireless Networks: A Survey of Issues and Solutions," Technical Report, Department of CSE, Indian Institute of Technology, Madras, India, March, 2003.

[5] Li Aslam, J. Rus D, "Online Power aware Routing in Wireless Ad-hoc Networks," International Conference on Mobile Computing and Networking.MobiCom'2001.

[6] Stojmenovic I , Lin X. "Power Aware Localized Routing in Wireless Networks," IEEE Transaction on Parallel and Distributed Systems 2001, 12(11):1122-1133.

[7] K. Woo, C. Yu, H. Y. Youn, and B. Lee, "Non-Blocking Localized Routing Algorithm for Balanced Energy Consumption in Mobile Ad Hoc Networks", Int'l Symp. on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS 2001), pp. 117-124, August, 2001.

[8] C-K Toh, "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.

[9] Hai Liu, Deying Li, Xiaohua Jia, "QoS Topology Control with Minimal Total Energy Cost in Ad Hoc Wireless Networks," in Proceedings of The Second International Conference on Mobile Ad Hoc and Sensor Networks (MSN 2006), Hong Kong, Dec. 2006.

[10] X.Y. Li, W.Z. Song and W. Wang, "A Unified Energy Efficient Top. for Unicast and Broadcast,"ACM MobiCom, 2005.

[11] Vinay Rishiwal 1, Mano Yadav2 , S. Verma3, S. K. Bajapai4 "Power Aware Routing in Ad Hoc Wireless Networks" JCS&T Vol. 9 No. 2 October 2009.

[12] M. K. Simon, J. K. Omura, R. A. Scholtz and B. K. Levitt, Spread Spectrum Communications Handbook. New York: McGraw-Hill, 1994.

[13] E. S. Sousa and J. A. Silvester, "Spreading code protocols for distributed spread spectrum packet radio networks", IEEE Transaction on Communications, vol. 36, no. 3, pp. 272–281, March 1988.

[14] M. K. Simon, J. K. Omura, R. A. Scholtz and B. K. Levitt, Spread Spectrum Communications Handbook. New York: McGraw-Hill, 1994.