International Journal of Computer Networking, Wireless and Mobile Communications (IJCNWMC)
ISSN 2250-1568
Vol. 3, Issue 2, Jun 2013, 35-42

ENERGY SAVING CONTROL IN AD HOC WIRELESS NETWORKS

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ABSTRACT

In this work, a new methodology is introduced for energy saving control problem in ad hoc wireless networks. The objective function is minimizing the variance of the power vector for the topology nodes. Inputs are given as a set of nodes in a plane, end-to-end traffic demands and delay bounds between node pairs, the problem is to find anoptimized routing that can meet the Quality of Service requirements and the variance of thepower vector for the nodes is minimized. The non-splitting case is considered. In this case the traffic demands are not splittable. The problem is formulated as an integer linear programmingproblem. An optimal algorithm has been proposed to solve the problem. The proposed model can be adopted for different topology with different request demands.

KEYWORDS: QoS Provisions, BroadcastIncremental Power (BIP), Multicast Incremental Power (MIP)

INTRODUCTION

The routing in ad hoc wireless network is considered one of the important issues.Communication between two nodes that are not direct neighbors requires the relay of messages by the intermediate nodes between them. Each node acts as a router, as well as a communication end-point.It is a special type ofwireless networks.Many studies have been done on QoS provisions in ad hoc networks, such as QoS routing or admission control [3]. Most of the existing works deal withresource allocation (e.g., scheduling or buffering) orrouting for QoS requests. Inmulti-hop ad hoc networks, on-line QoS provisions, such as end-to-end bandwidth and delay, are highlydependent on the network topology. A properconfiguration of the topology is required, in order to get a good QoS.The topology of an ad hoc network can be controlledby some "controllable" parameters such as transmittingpower and antenna directions. Topology control is toallow each node in the network to adjust its transmittingpower (i.e., to determine its neighbors) so that a *good*network topology can be formed. An issue associatedwith topology control is often energy management. In adhoc wireless networks, each node is usually powered bya battery equipped with it. Since the capacity of batterypower is very much limited, energy consumption is amajor concern in topology control. To increase thelongevity of such networks, an important requirement oftopology control algorithms is to achieve the desiredtopology by using minimum energy consumption.In this paper, we study the energy efficient QoS topology control problem. Given a set of wireless nodesin a plane and QoS requirements between node pairs,our problem is to find a network topology that can meet the QoS requirements and the totaltransmittingpower of nodes is minimized. The QoS requirements of our concern are traffic demands (bandwidth) andmaximum delay bounds (in terms of hop counts) between end-nodes at the application level. With thenetwork configured in such a topology, as many as possible QoS calls can be admitted at run-time and thenetwork life time can be extended.

RELATED WORK

There are some research works that have alreadybeen done on topology control for ad hoc wirelessnetworks. The earlier works of topology control can befound in [2, 11, 12]. An analyticmodel was developed to allow each node to adjust itstransmitting power to reduce interference and henceachieve high throughput. In some research works, a distributed algorithmwas developed for each node to adjust its transmittingpower to construct a reliable high-throughput topology.Minimizing energy consumption was not a concern inboth works.Recently, energy efficient topology control becomesan important topic in ad hoc wireless networks. Most ofthe works have been focused on the construction andmaintenance of a network topology with good (orrequired) connectivity by using minimal powerconsumption. Lloyd *et al.* gave a good summary of theworks in this type in [4]. They use a 3-tuple <M, P, O>to represent topology control problems, where “M”represents the graph model (either directed orundirected), “P” represents the desired graph property(e.g., 1-connected or 2-connected), and “O” representsthe minimization objective. The NP-completeness of this kind ofproblems has been analyzed and several algorithms havebeen proposed. In [4, 6], two centralized optimalalgorithms were proposed for creating connected and biconnected static networks with the objective ofminimizing the total transmitting power for the nodes. Additionally, two distributed heuristics, LINT(local information no topology) and LILT (localinformation link-state topology), were proposed foradaptively adjusting node transmitting power tomaintain a connected topology in response totopological changes. But, neither LINT nor LILT canguarantee the connectivity of the network. Li *et al.*proposed a minimum spanning tree based topologycontrol algorithm that achieves network connectivitywith minimal power consumption [9]. A cone-baseddistributed topology control method was developed in[10]. Basically, each node gradually increases itstransmitting power until it finds a neighbor node inevery direction (cone). As the result, the globalconnectivity is guaranteed with minimum power foreach node. Huang *et al.* extended this work in [12] to thecase of using directional antennas [11]. Another method to optimize the topology ofBluetooth depends on minimizing the maximumtraffic load of nodes (thus minimizing the totalpower consumption of nodes).There are a lot more works on energy efficientcommunication in ad hoc wireless networks, such as in[13, 14]. The goal is to choosethe transmit power level, so that low power levels can beused for intra-cluster communication and high powerlevels for inter-clusters. Some heuristicalgorithms were proposed, namely the BroadcastIncremental Power (BIP), Multicast Incremental Power (MIP) algorithms, MST (minimum spanning tree), andSPT (shortest-path tree). The proposed algorithms were evaluated through simulations. So far, there is no published work that considers howto meet the overall QoS requirements through topologycontrol. In this paper, we address the problem oftopology control that can meet the QoS requirements and the totalconsumed power of nodes in the system isminimized.

SYSTEM MODEL AND PROBLEM SPECIFICATION

In this work, a group of notations will be used. We adopt the widely used transmitting power modelfor radio networks: $p_{ij} = \langle d_{i,j}$, where p_{ij} is the transmitting power needed for node i to reach node j,$d_{i\,j}$, is the distance between i and j, and 〈 is aparameter typically taking a value between 2 and 4.The network is modeled by $G = (V, E)$, where V isthe set of n nodes and E a set of undirected edges. Eachnode has a bandwidth capacity B, and a maximal level of transmitting power P_{max}. The bandwidth of a node is shared for both transmitting and receiving signals. That is, the total bandwidth for transmitting signals plus thetotal bandwidth for receiving signals at each node shallnot exceed B. Let pi denote the transmitting power ofnode i. We assume that each node can adjust its powerlevel, but not beyond some maximum power P_{max}. The connectivity between two nodes depends on their transmitting power.

From the network model, we can see that thenetwork topology can be controlled by the transmittingpower at each node and the topology directly affects the QoS provisions of the network. If the topology is toodense (*i.e*., nodes have more neighbors), there would bemore choices for routing, but the power consumption ofthe system would be high. On the other hand, if thetopology is too loose (*i.e*., with less edges), there wouldbe less choices for routing (hence, some nodes could beover-loaded) and the average hop-count between endnodeswould be high. Our goal is to find a balanced topology that can meet end-users QoS requirements andhas minimum energy consumption. Let $\lambda_{s,d}$ and $\Delta_{s,d}$ denote the traffic demand and the maximally allowed hop-count for node pair (*s*, *d*),respectively. Let P_{max}= max{p_i | 1 $\leq i \leq n$}. The topology control problem of our concern can be formally defined as: given a node set *V* with their locations, $\lambda_{s,d}$ and $\Delta_{s,d}$ for node pair (*s*, *d*), findtransmitting power *pi* for 1 $\leq i \leq n$, such that all the traffic demands can be routed within the hop-countbound, and *the total consumed power* is minimized.We consider one case, end-to-end traffic demands are not splittable, i.e., $\lambda_{s,d}$ for node pair (*s*, *d*)must be routed on the same path from *s* to *d*. We assume each node can transmit signals to itsneighbors in a conflict free fashion. Thus, we do notconsider signal interference in this paper.

TOPOLOGY CONTROL WITH TRAFFICS NONSPLITTABLE

Given

- *V*, set of *n* nodes and their locations.
- *B*, the bandwidth of each node.
- $\lambda_{s,d}$, traffic demands for each node pair (*s*, *d*).
- $\Delta_{s,d}$, maximally allowed hop-count for node pair(*s*, *d*).
- P_{max}, maximally allowed transmitting power of nodes.

Variables

- x_{ij} is a boolean variables, x_{ij}=1 if there is a linkfrom node *i* to node *j*; otherwise, x_{ij}= 0.
- x_{ij}^{sd} is a boolean variables, x_{ij}^{sd}, =1 if the routefrom *s* to *d* goes through the link (*i*, *j*); otherwise x_{ij}^{sd} = 0.
- P_{max} , the maximum allowed power of nodes.

Optimize

- Minimize the total transmitting power ofnodes.*Min Total consumed power* (1)

Constraints

- **Topology Constraints**

$$x_{i,j} = x_{j,i} \qquad \forall\, i,j \in V \quad (2)$$

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

$$x_{i,j} \leq x_{i,j'} \;\; if \;\; d_{i,j'} \leq d_{i,j} \quad \forall\, i,j,j' \in V \quad (3)$$

Constraint (3) ensures that nodes have broadcast ability. That is, the transmission by a node can be received by all the nodes within its transmitting range. This feature can be represented by the links in the network as: for node *i*, if there is a link to *j* (*i.e.*, $x_{i,j}$ = 1), then there must be a link to any node *j*' (*i.e.*, $x_{i,j'}$ = 1) when $d_{i,j'} \leq d_{i,j}$, which is constraint (3).

- **Transmitting Power Constraints**

These group of constraints must be satisfied for all nodes, which have two parts. The first part means that the total consumed power for each node still below the maximum allowable value for each one. The second part means that the required consumed power should be more than $d_{i,j}^{\propto} x_{i,j}$

First Part

$$P_{totalconsumed} \leq P_{max} \forall i < j, i, j \in V \quad (4)$$

Second Part

$$P_{reserved} \geq d_{i,j}^{\propto} x_{i,j} \forall i < j, i, j \in V \quad (5)$$

- **Delay Constraints**

$$\sum_{(i,j)}' x_{i,j}^{s,d} \leq \Delta_{s,d} \forall (s,d) \quad (6)$$

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

- **Bandwidth Constraints**

$$\sum_{(s,d)}' \sum_{j}' x_{i,j}^{s,d} \lambda_{s,d} + \sum_{(s,d)}' \sum_{j}' x_{j,i}^{s,d} \lambda_{s,d} \leq B \forall i \in V \quad (7)$$

It ensures that the total transmission and reception of signals at a node do not exceed the bandwidth capacity of this node. The first term at the right hand side of inequality (6) represents all the outgoing traffics at node *i* (transmitting) and the second term represents all the incoming traffics(reception).

- **Route Constraints**

$$\sum_{j} x_{i,j}^{s,d} - \sum_{j} x_{j,i}^{s,d} = \begin{cases} 1 & if \quad s = i \\ -1 & if \quad d = i \\ 0 & otherwise \end{cases} \forall i \in V \quad (8)$$

$$x_{i,j}^{s,d} \leq x_{i,j} \qquad \forall i,j \in V \quad (9)$$

- **Binary Constraint**

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

Constraints (8) and (9) ensure that the validity of the route for each node-pair. Since, traffics are not splittable, $x_{i,j}^{s,d}$ represents that the entire traffics of (*s*, *d*) go through link (*i*, *j*). The availability of bandwidth along the route is ensured by constraint(6). The problem of QoS topology control for nonsplittable has now been formulated as an integer linear programming problem (ILP) (1)-(10), which is NP-hard in general. In this work Matlab 9 is used to solve this problem.

OUR NEW CONSTRAINTS

The main objective of this work is to add a new constraints to the previous to affect the transmitted power consumption distribution. In other word, reduce the variance of the power matrix. The idea of this constraint is to force the system to use the minimum previous used nodes. So, it can just use the nodes which had consumed less than the average consumed power. The first problem with this constraint is that it tighten the system and find no solution specially in the beginning (the power matrix is zeros). In order to relax this constraint a threshold value is added to include more nodes above the average consumed power. Another problem is that the average in first request is zero which is equal to the transmitting power for all the nodes. So, this constraint is activated after three requests to avoid this problem.

$$P_i \leq P_{average} + Threshold \quad \forall\ 1 \leq i \leq n \ (11)$$

The following sections discuss the optimum threshold value and a comparison between different threshold values, finally, a comparison between with and without this constraint.

EXPERIMENTS

Simulation Setup

The simulations are conducted in a 30×30 twodimensionalfree-space region. The assumed number of nodes is set to be 15, for simplicity. The model is simulated to accept any number of nodes but with more time complexity. The co-ordinates of thenodes are randomly and uniformly distributed inside theregion. All nodes have the same bandwidth capacity B =500. The value of $\propto$ in the transmitting power functionis set to 2. The set of requests $R = \{(s, d, \lambda_{s,d})\}$ are generatedby 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 $\lambda = 1$ to generate a number k, which is the number of requests originating from this node. The destinations of the k request are randomly picked fromthe other nodes. The traffic demand $\lambda_{s,d}$ for a pair of nodes (s, d) is assigned by a random function of anormal distribution with variance equal to 0.5μ_m, where μ_m is the mean value of the normal distribution function. Figure 1 shows the input chosen topology with number of nodes n=15in 30×30 meter. The model is simulated as an Integer Linear programming problem using matlab with the previous equation (1-11) include our new constraint.

The first issue for this fixed topology is to find the optimum threshold.

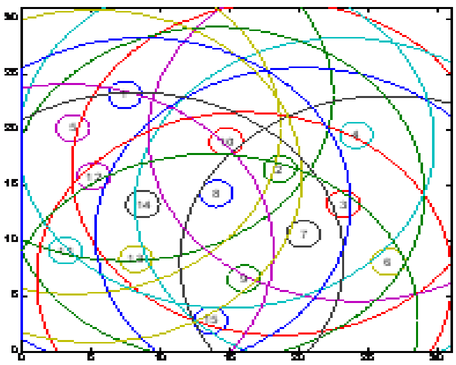

Figure 1: The Input Topology Number of Nodes n=15 in 30x30 Meter

Simulation Results and Analysis

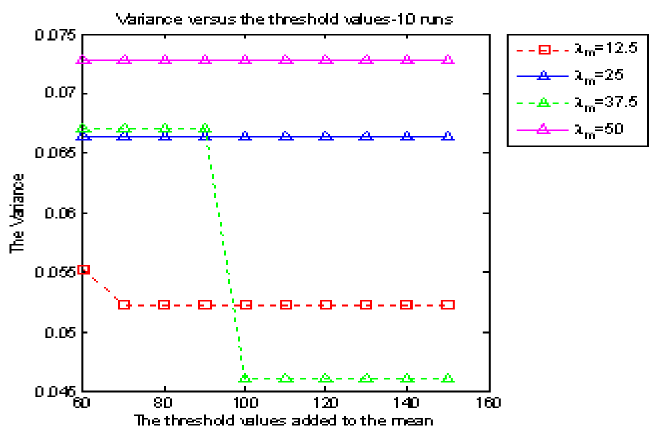

Figure 2: Normalized Variance versus Threshold Values with Different λ_m Values (12.5, 25, 37.5, and 50)

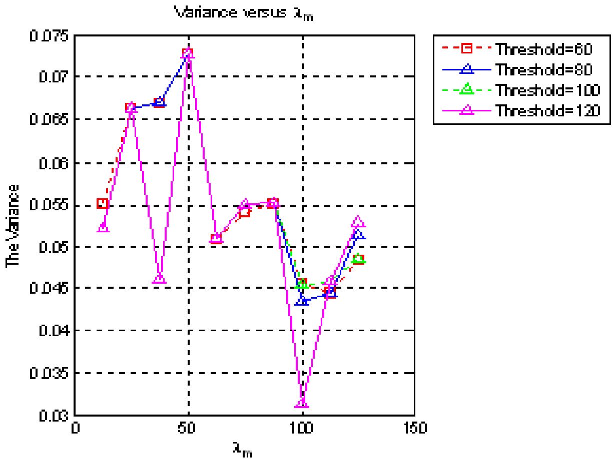

Figure 3: Normalized Variance versus λ_m Values with Threshold Values (60, 80,100, and 120)

We run this model ten times for each time different group of requests, each run is a time value T≈17 sec, in other words ***T1=T, T2=2×T, …, T10=10×T (T1 to T10)***.This is repeated for each threshold value as shown in figure 2, (60 to 150 with step 10, 10 values). λ_m value affect the result of the variance. The minimum packet loss for the same group of packets is minimum for λ_m=50, the worst case λ_m =25. Also, figure 2 depicts the minimum variance at threshold more than or equal to 100 for λ_m =37.5. Figure 3 emphasize the minimum normalized variance at λ_m =100 and threshold 120. From these figures, it is obvious that this problem is an optimize problem. The higher value for threshold enhances the QoS. Also the lower λ_m is better for the performance.

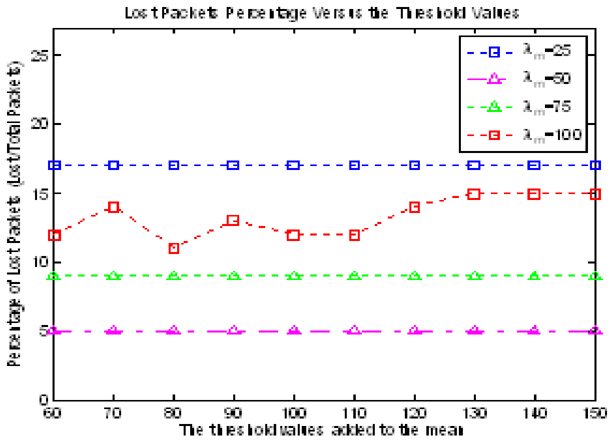

Figure 3: Lost Packets versus the Threshold Value

Table 1 shows the routing solution to minimize the power for a group of requests at time t=T6. This results for threshold value equal to 90 and λ_m=112.5. Table 2, For the same group of requests at the same time T6 and $\lambda_m$but without threshold. It can be shown the effect of threshold change by different routing at requests 5, 11, 14, 15, and 16. Also, the normalized variance is changed from **0.044438 to 0.081247**.

Table 3: describes the effect of increasing the threshold for the same group of requests.

Table 1: λ_m =112.5, Threshold =90 at t=T6, Variance=0.044438

Req. #	λ_{sd}	S	d	Routing Path
1	120	1	2	1-->10-->2
2	101	1	5	1-->5
3	105	2	7	2-->7
4	116	3	13	3-->2-->8-->14-->13
5	124	3	14	3-->7-->9-->13-->14

Table 1: Contd.,				
6	110	3	5	3-->7-->9-->13-->14-->12-->5
7	109	5	8	5-->12-->14-->8
8	111	7	3	7-->3
9	118	7	13	7-->9-->13
11	111	8	13	Lost
12	107	9	8	9-->8
13	116	10	8	10-->8
14	113	12	7	12-->5-->1-->10-->2-->3-->7
15	108	13	9	13-->11-->15-->9
16	115	13	4	13-->9-->7-->3-->4

Table 2: λ_m =112.5, without Threshold at t=T6, Variance=0.081247

Req. #	λ_{sd}	S	d	Routing Path
1	120	1	2	1-->10-->2
2	101	1	5	1-->5
3	105	2	7	2-->7
4	116	3	13	3-->2-->8-->14-->13
5	124	3	14	3-->2-->8-->14
6	110	3	5	3-->7-->9-->13-->14-->12-->5
7	109	5	8	5-->12-->14-->8
8	111	7	3	7-->3
9	118	7	13	7-->9-->13
11	111	8	13	8-->14-->13
12	107	9	8	9-->8
13	116	10	8	10-->8
14	113	12	7	12-->14-->8-->7
15	108	13	9	13-->9
16	115	13	4	13-->14-->8-->2-->4

CONCLUSIONS

The threshold constraint emphasizes a great effect on the routing decision. The variance is decreased compared with the model without the threshold value. The results are affected with the λ_m variation. The higher λ_m The more instability of the system (more packet loss). The optimum threshold value is found to be 5×m, where m is the size of the network. The more dense of the network (increase of number of nodes), the more effectiveness of our constraint which decrease the variance. In consequence this will extend the network lifetime.

Table 3: λ_m =112.5, Threshold =100 at t=T6, Variance=0.044438

Req. #	λ_{sd}	S	d	Routing Path
1	120	1	2	1-->10-->2
2	101	1	5	1-->5
3	105	2	7	2-->7
4	116	3	13	3-->2-->8-->14-->13
5	124	3	14	3-->2-->10-->14
6	110	3	5	3-->2-->10-->1-->5
7	109	5	8	5-->12-->14-->8
8	111	7	3	7-->3
9	118	7	13	7-->9-->13
11	111	8	13	Lost
12	107	9	8	9-->8
13	116	10	8	10-->8
14	113	12	7	12-->13-->9-->7
15	108	13	9	13-->11-->15-->9
16	115	13	4	13-->9-->7-->3-->4

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