Energy Efficient Greedy Algorithm for Wireless Mesh Networks

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ABSTRACT

Aim: Wireless Mesh Networks (WMN's) are gaining recognition among users. But WMN resources are not always utilized up to their full capacity. Redundant links and nodes can be turned in low power state for energy savings. WMN's build on IEEE 802.11s, supports link based power saving mode (PSM). But IEEE 802.11s standard does not specify switching among PSM. This research work provides a greedy approximation algorithm to allow redundant nodes and links in low power state to achieve minimum energy consumption.

Methodology: Proposed algorithm is based on traffic consolidation over few nodes, subject to available link slots due to wireless interference. This will permit redundant nodes in deep sleep mode.

Results: Analysis reveals that choosing power saving mode carefully of peer links can achieve great energy efficiency.

Conclusion: Results signifies that energy saving comes with cost of delay. So traffic consolidation based approaches are more suitable for delay tolerant networks.

Key Words: Energy Efficient, Wireless Mesh Network, Power Saving Mode, Greedy Approach, Traffic Consolidation

INTRODUCTION

With increasing usage to digital devices and need of access to Internet from anywhere, Wireless Mesh Networks (WMN's) are gaining popularity among community. WMN can be designed based on various wireless standards like IEEE 802.11a/b/g/s IEEE 802.16, IEEE 802.15 etc. IEEE 802.11s is specially designed to support features of WMN. Unlike previous standard of IEEE 802.11, IEEE 802.11s supports link based power saving mode (PSM) namely light sleep mode, deep sleep mode, and active mode. PSM of link of a node can be chosen independent of PSM value of other links. But standard itself does not specify PSM switch criteria. In order to save network energy a feasible approach is desired so that redundant resources can be switched in low power state. To identify and allow redundant nodes in low power state, by solving mathematical problem as mixed linear programming problem [1-2] can be computationally expensive and practically not feasible. A greedy algorithm as an approximation to optimized solution can be a valuable approach. The energy aware greedy routing algorithm based on resource consolidation, subject to available link slots due to wireless interference has been proposed. Traffic consoli-

dation is an approach where traffic of several underutilized nodes is consolidated to few active nodes. Algorithm will allow many nodes in doze state so that system capacity could be utilized efficiently. The performance of the proposed algorithm has been evaluated and analyzed.

The remaining of text is structured as follows. Section II presents related area of work, Section III presents greedy algorithm to achieve PSM for links to let maximum nodes in deep sleep mode. Section IV gives results and Section V provides the discussion. Finally, concluding remarks are presented in section VI.

Related Works

Energy Efficient WMN is active area of studies, number of research work exist in literature. Ashraf [3] has proposed a heuristic based greedy algorithm for placement of gateway in WMN in energy efficient way. The known traffic demands are satisfied while minimizing the overall energy usage of the network. Yu et al. [4] have given energy-aware design of the network selection, sub channel, and power assignment in cellular and Wi-Fi networks. Researchers in [3-4] have focused on energy minimization by network designing. While

authors in [5] reduces energy consumption by accessing information of medium access layer via control packet. In [6] authors have enhanced the network life time by shutting down the unnecessary nodes. The nodes to be shutdowns are identified based on threshold distance. A node can decide to shutdown itself if its distance to neighbor node is within threshold distance. Performance of network highly depends on selected value for threshold distance. Ismail et al. [7] have given cooperation based approach so that networks with overlapping coverage may cooperate to let others switch off.

But traffic consolidation subject to link availability has not been given due considerations. Keeping in view of growing interest in energy efficient WMN this research work focuses at providing greedy algorithm to consolidate the determined traffic over few nodes in energy efficient way subject to link slot availability.

Table 1: Summary of Notations

Notation	Definition
S	Number of time slots in a frame
l	Number of links in graph
T_E	Energy used in transmitting a packet
R_E	Energy used in receiving a packet
B	Bandwidth
E_{Node}	Energy consumed at a MR
N	Set of all nodes in network
G	Set gateway node
A	Set mesh access point
L	Set links
T	Set traffic demands from mesh access points
M	Set of mesh routers

Research Methodology

A greedy algorithm has been proposed for network having nodes with sufficient power supply. Here objective is to reduce energy consumption of overall network.

Definition 1- Allocation matrix $AL_{S*l} = \{a_{i,j}\}\ 1 \leq i \leq S, 1 \leq j \leq l$ is a matrix with rows given by number of time slots in a frame and columns determined by number of links in graph MN. Value of any element in matrix $a_{i,j}$ identifies if links j has been allocated time slot i.

Where, $a_{i,j} = 1$, means link j is allocated slot i,

$a_{i,j} = 0$, signifies link j is available but not allocated slot i,

$a_{i,j} = -$, signifies link j is in conflict with slot i.

Definition 2- Flow matrix $FL_{S*l} = \{f_{i,j}\}\ 1 \leq i \leq S, 1 \leq j \leq l$ is a matrix with number of rows and columns given by number of time slots in a frame and number of links in graph MN respectively. Value of any element in matrix $f_{i,j}$ identifies scheduled flow during slot i on link j.

$$load_n = \sum_{i=0}^{S} f_{i,j} \ \forall\ j \text{ incident on node } n \quad (1)$$

Energy_Aware_Resource_Consolidation (Algorithm 1) consolidates the traffic over minimum number of nodes in energy efficient way, to allow maximum number of links and nodes in energy saving mode. Load is redistributed by co-operation among neighbor nodes to let maximum link and nodes in low power state. Under law of wireless interference, algorithm firstly computes shortest path in term of energy towards gateway nodes using Minimum_Energy_Route (Algorithm 2). Active degree of any nodes **i** is computed based on incoming $\{l_{i,j}\}$/outgoing links $\{l_{j,i}\}$, which in turn is given by number of 1 in corresponding column on AL_{S*l}. Redundant nodes identified using step 2 and 3 are set in doze state and their associated links in deep sleep mode. A list of nodes in increasing order of load is computed. For traffic consolidation, least loaded node is picked for adjustment of their traffic over existing active nodes. Based on greedy assumption that re-adjustment of lower loaded nodes will be more feasible and beneficial in terms of energy. If load can't be adjusted then traffic of next least loaded node in list is re-adjusted and so on till we reach at end of list. If all traffic of such node can be rerouted successfully then least loaded node is set to doze state and their associated links in deep sleep mode. Then updated list of nodes is sorted in increasing order of load. Minimum_Energy_Route (Algorithm 2) finds best available route with minimum energy consumption based on available slots as per law of wireless interface under single channel. Algorithms 3 address feasibility of traffic on a link to be routed.

Algorithm 1: A greedy algorithm for Energy_Aware_Resource_Consolidation

Input: A communication directional graph MN (L,M,G,A,T), N=M ∪ G ∪ A.

Complexity O(|N|*|L|* (|N|+|L|))

Output: A minimum energy communication graph.

1. Compute energy weight of links $W = \{w_{ij}\}$ on graph MN, given by T_E and R_E per packet
   Set $color(x) = \ 'white'\ \forall x \in N$
   $Status(x) = \ 'active'\ \forall x \in N$
   $PSM(l) = \ 'active\ mode'\ \forall\ l \in L$
   $P = NULL$

Initialize allocation matrix, $AL_{S*l}[i, j] = 0 \ \forall\ i \in 1..S, j \in 1..l$.
Initialize Flow matrix $FL_{S*l}[i, j] = 0 \ \forall\ i \in 1..S, j \in 1..l$.

Initially no node is communicating and all slots are available for communication

2. A) Call Minimum_Energy_Route(N,G,A,L,T), for minimum shortest path based on energy consumption $P = \{p_{a_i}\}$, subject to law of wireless interference
   B) Compute load of nodes using eq. (1).
   C) Compute degree of active links of all nodes in MN

3. For all nodes $n \in N$
   If (activedegree(n)=0)
   $I = \{l_{i,j}\}$, set of outgoing or incident links on n

   Set $AL_{s*l}[i,j] = d \; \forall i = 1 \ldots S, j \in I, status(n) = 'doze'$
   Update N=N-{n}, L=L-I.

4. Compute degree of active links of all nodes in MN

5. Empty S. Push nodes in decreasing order of load and number of active links in stack S

6. POP S to get node $'x'$ with $color = 'white'$ and not null load
   If $POP(S) = NULL$
   Display 'No more traffic consolidation possible'
   Go to step 9.
   Else
   $I = \{l_{i,j}\}$, set of outgoing or incident links on x

   Update $N' = N - \{n\}$, $L' = L - I$,
   $Prev\_AL_{S*l} = AL_{S*l}$

   $Prev\_P = P$

7 (A) Call Minimum_Energy_Route (L,M,G,A,T)
  (B) Compute load of nodes using eq (1)

8. If feasible path for all flows via $'x'$ found then
   Accept the solution of traffic reconsolidation
   Update $N = N'$, $L = L'$, $Status(x) = 'doze'$
   $PSM(l) = 'deep\ sleep\ mode'\ \forall l \in I$
   Set status of links in P' for allocated slots in active mode to each other
   Go to step 4
   Else
   If feasible path for all flows via $'x'$ is not found on MN
   Reject the redirected path for all flow on set $\{f_i\}$
   $AL_{t*l} = Prev\_AL_{t*l}$

   $P = Prev\_P$

   Set Color(x) = 'black'.
   Go to step 6.

9. Compute energy consumption of network.

Algorithm 2. Minimum_Energy_Route (L,M,G,A,T)

Input: A communication directional graph MN (L,M,G,A,T), $N = M \cup G \cup A$

Output: Minimum energy paths from multiple access point to gateway subject to available continuous link capacity due to interference model.

1. For $\forall t_{S,G} \in T$ repeat steps 2-5.

2. Find set of all paths P' from source to gateway node along with communication energy cost per packet using depth first search algorithm [8]
   $P = P\ union\ P'$

   Empty S.
   Push path P' with $status\ != full$ along with source node i in stack S in decreasing order, (Top will point to path with minimum energy)

3. Pop S to give path $P_{S,G} = \{l_{S,G}\}$. Here, $'s'$ is MAP having minimum path cost
   If $POP(S) \neq NULL$ Perform steps 4 to 5. Else go to step 6

4. Call Feasible_Path to route, scheduled traffic $t_{S,G}$ on ($P_{S,G}$) and get feasible_flow

5. If (feasible_flow>0 and feasible_flow<$t_{S,G}$)
   $t_{S,G} = t_{S,G} - feasible\_flow$, set status $(P_{S,G}) = full$.
   Go to step 3

6. If there still a MAP with not null traffic $t_{S,G}$
   Display 'Capacity of links is not enough to accommodate all traffic of node x'.
   Else
   Display 'all traffic of node x' is routed and scheduled successfully'

7. Update FL_{t*l}.

Definition 3- Unit of flow $u = \lceil \frac{n}{x} \rceil$ where, n is number of packets to be transmitted and x is number of packets that can be transmitted over a time slot.

Algorithm 3. Feasible_Path ($P_{S,G}$)

Output: Feasibility flow on a link.

1. Compute unit of flow u.
2. Set Feasible_flow=0.
3. For $i = 1 \ldots u$

   3.1. $\forall l_{p,q} \in P_{S,G}$ perform following steps

   Search Allocation matrix AL_{t*l} from 1 to S, under column of $l_{p,q}$ for $a_{i,j} = 0$
   Set $a_{i,p} = a_{i,q} = 1$,
   Update allocation matrix for interference on other links as per law of wireless interference.

   3.2. If slot i has been identified successfully
   Set Feasible_flow= Feasible_flow+x
   Else
   Capacity of path is full
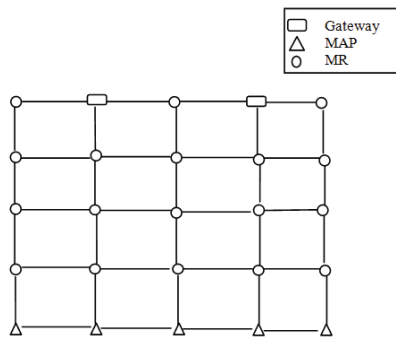   Set Feasible_flow= 0
   Break

4. Return Feasible_flow.
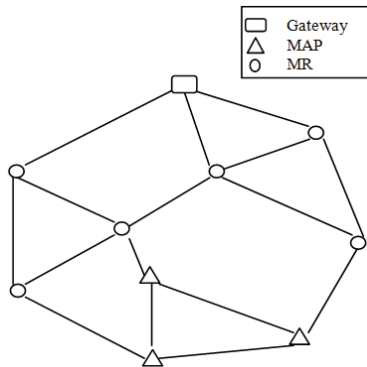
Figure 1: Grid topology of 25 nodes.

Figure 2: Small random topology of 10 nodes

RESULTS

Algorithm has been implemented in C++. Multiple runs reveal that algorithm is energy efficient. 30 slots per frame have been assumed for simulation. Let energy used in transmitting a packet is 3.1 mJ, energy used in receiving a packet is 0.2 mJ, and energy consumption of an MR is 15W. Considering network topology given in figure 1 and 2. Let network have single channel to operate. As per law of wireless interference network will be highly congested if traffic at all MAP's exceed 10 packets. Results for random and grid topology are given in Table 1 and Table 2.

DISCUSSION

By reducing redundant peer links energy saving can be enhanced in 802.11s. Analysis reveals that choosing PSM carefully of peer links can achieve great energy efficiency. As solving the optimization problem can be computationally expensive. So, greedy based approach can be very effective. During low traffic period more resources are underutilized, so algorithm can let more links and nodes in deep sleep mode. But when traffic is close to peek level, resources are utilized up to their maximum capacity and percentage of energy saving reduces.

Table 2: Results for small topology network

Number of packets at MAP	After Algorithm		Before Algorithm		Percentage of energy saved	Percentage of transmission delay increased
	Active MR	Sleeping MR	Active MR	Sleeping MR		
1	2	4	6	0	67	22
2	2	4	6	0	67	22
3	2	4	6	0	67	22
4	2	4	6	0	67	22
5	2	4	6	0	67	22
6	4	2	6	0	34	11
7	4	2	6	0	34	11
8	4	2	6	0	34	11
9	4	2	6	0	34	11
10	6	0	6	0	0	0
>10 (Network will be highly congested)	6	0	6	0	0	undefined

Table 3: Results for Grid topology network

Number of packets at MAP	After Algorithm		Before Algorithm		Percentage of energy saved	Percentage of transmission delay increased
	Active MR	Sleeping MR	Active MR	Sleeping MR		
1	4	14	18	0	78	52
2	4	14	18	0	78	52
3	4	14	18	0	78	52
4	8	10	18	0	56	26
5	8	10	18	0	56	26
6	12	6	18	0	34	17
7	12	6	18	0	34	17
8	18	0	18	0	0	0
9	18	0	18	0	0	0
10	18	0	18	0	0	0
>10 (Network will be highly congested)	18	0	18	0	0	undefined

CONCLUSION

This work represents importance of wireless mesh network in today network. PSM of IEEE 802.11s can achieve great energy saving. According to IEEE 802.11s standard a mesh node may choose to enter in doze state (in doze state a mesh node may switch off the transceivers) for power saving only if the mesh STA operates in light sleep mode or deep sleep mode for all of its mesh peering. A greedy algorithm has been proposed to minimize energy consumption. Results reveal that algorithm is effective in reducing energy consumption of network, but comes with cost of increase in traffic delay. So traffic consolidation approaches are more suitable for delay tolerant network.

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