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A FRAMEWORK FOR CONSERVING POWER IN MANETS

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Abstract

The idea of using controllable relay nodes for designing mobile systems has been explored by several researchers. The main objective of this paper is to design a framework for deploying relay nodes with controlled mobility to conserve power in MANET. To meet out this proposal, a heterogeneous network consisting of traditional nodes with limited energy and relay nodes with more energy resources are considered. The deployment of relay nodes are based on the following two methods: 1. Min-Total, aims to minimize the total energy consumption of all the traditional nodes in the network. 2. Min-Max, aims to minimize the energy consumed by a traditional node in the network. The solution of these two methods can be used to prioritize each individual node in the network. The trade-offs involved in deploying an increasing/decreasing fraction of relay nodes, varying node weights, varying epoch duration is analyzed. This framework aims at dynamically combining both Min-Total and Min-Max based on the characteristics and requirements of the network.

Keywords-MANETs, Energy Efficiency, controlled mobility.

1 INTRODUCTION

Mobile Ad-hoc Networks (MANETs) refer to a collection of hosts communicating over a wireless channel. MANETs are gaining popularity because of ease of deployment. MANET is a decentralized infrastructureless network and the nodes move arbitrarily. The nodes communicate either directly or through multihops. MANETs face various problems like unpredictable topology, increased interference and congestion, and limitation of resources like bandwidth and energy due to shared wireless medium and its dynamic nature. Nodes within an ad hoc network generally rely on batteries (or exhaustive energy sources) for power. Since these energy sources have a limited lifetime, power availability is one of the most important constraints for the operation of the ad hoc network.

There are different sources of power consumption in a mobile node-Energy consumed while sending a Packet- Energy consumed while receiving a packet- Energy consumed while in idle mode- Energy consumed while in sleep mode which occurs when the wireless interface of the Mobile node is turned off. Power utilization can be optimized by employing routing algorithms that avoid nodes with less battery power remaining while trying to minimize the total power consumed in transmitting a packet. In mobile adhoc network there are three aspects to reduce the power consumption.- Power saving at mobile device level , Power saving by controlling transmission level of packet , Power saving by using optimized power routing protocol.

In this paper a heterogeneous network consisting of traditional nodes and relay nodes is considered. Mobile relay nodes are used to minimize power consumption in MANETs. Relay nodes are costly, more powerful and their main task is communication with other nodes. Relay nodes have same transmission radii. Nodes consume more power when it is actively transmitting data packets compared to packet reception and idle periods. Also transmission over long distances consumes power more power compared to short distance transmissions.

Power consumption is minimized by using relay nodes as intermediate nodes and transmit data over shorter distances. The objective of the framework is to efficiently deploy the relay nodes in the network so that the traditional nodes utilize them as intermediate hops for communication. These intermediate hops allows the traditional nodes to transmit data at reduced power.

The heterogeneous mobile adhoc network compromises on the energy consumed at the relay nodes in order to minimize the energy consumed at the traditional nodes. The relay node can be placed closer to the traditional node to minimize the energy consumed during packet transmission. In this paper two, methods of the relay deployment problem, together with their solutions is presented.

2 ENERGY MODEL

In wireless networks, communication takes place over multihop path. The data flow between source and destination nodes can be represented as a set of one hop flows between adjacent nodes. Let T be the set of traditional nodes and R represents the set of mobile relay nodes. F be the set of all one hop flows. Each flow is represented as fi=(si,di,λi), i=1,2….N, where si is the source node, di is the destination node and λi is the data rate. The energy consumed at the source node by a flow fi per unit time is given by

$$E_i = \lambda_i * P_T(\delta_{si\ di})$$

where P_T is the energy needed for transmitting one bit of data between nodes. Energy function P_T is usually given as $P_T=a+b\delta_{sidi}$, where a and b depends on the characteristics of the communication channel. δ_{sidi} is the distance between the source node and the destination node. Let F_r denote the service set of the relay node $r_j \epsilon R$. F_r consists of all the flows that are being relayed through the node r_j and $F_r \subseteq F$ .The energy consumed for data transmission per unit of time at node s_i for a flow belonging to the service set of the relay node s_i given by

$$E_i^j = \lambda_i * P_T(\delta_{si\ rj})$$

2.1 Min-Total Formulation

This formulation aims at minimizing the overall energy consumed across the traditional nodes in a service set. Here a relay node is placed in such a way as to minimize the overall energy consumed across all the traditional nodes in its service set. The total energy consumed by the traditional nodes in the absence of relay nodes for data transmission per unit time is given by

$$E_{tot} = \sum_{f_i \in F} E_i$$

The total energy consumed for data transmission by the traditional nodes in the presence of relay nodes is given by

$$E_{totr} = \sum_{j \in R} \sum_{f_i \in F_r} E_i^j + \sum_{f_k \in F - F_r} E_k$$

The total transmission energy consumed in a relay enabled network is dependent on the location of the relay nodes, location of the traditional nodes, set of flows in the network, combined service set of the relay nodes. The position of the relay node and the combined service set of the relay node are adjusted so that the overall energy consumed across the traditional nodes is minimum. The drawback of the Min-Total formulation is that the energy consumption across the individual nodes may be uneven.

2.2 Min-Max Formulation

The objective of the Min-Max formulation is to minimize the maximum transmission energy consumed across the traditional nodes in the network. The maximum energy consumed by a traditional node in the service set F_{rj} is given by

$$E_{\max}^j = \max_{i \in F_{r_j}} E_i^j$$

This formulation aims at minimizing E^j_{max} for the service set F_{rj} by finding the optimal position of the relay node. To accomplish this the best possible service set for every relay node has to be defined and computed.

2.3 Assigning node weights

In the above two formulations the relay node is placed closer to the source nodes with higher data flow rates. In some cases, it is recommended that the relay node favours the source node with low residual energy. Some nodes in a network will be utilized often and such nodes should be given more weightage to prolong the lifetime of the network.

These factors are included in the problem formulation by assigning a weight w_i to each flow $f_i \epsilon F_{rj}$. The weight w_i is the priority assigned to the flow f_i and is given by

$$w_i = z_1 * \epsilon_i + z_2 * p_i$$

where ϵ_i and p_i denotes the residual energy and contextual priority of the source node si corresponding to the flow f_i.z_1 and z_2 are the relative weights assigned to the residual energy and contextual priority by the network operator. Min-Total scheme after assigning node weights is given by

Figure 1. a) Data flows without using a relay node. **b)** Data flows after deploying a relay node

$$E_{totr} = \sum_{j\in R}\sum_{f_i\in F_r} w_i * E_i^j + \sum_{f_k\in F-F_r} w_j E_k$$

The optimization function of Min-Max scheme after assigning node weights is given by

$$E_{\max}^j = \max_{i\in F_{r_j}} w_i * E_i^j$$

3 STATIC NETWORK

We first describe the solutions for a static network and then present the solutions for a mobile network. The movement and positioning of the relay node depends on the position of the traditional nodes and the set of active flows between them. There are two steps to be carried out to solve the two problem instances: 1.find the optimal service set for every relay node. 2. compute the optimal position of the relay node based on the objective function. The two steps are closely related to each other and leads to a iterative solution instead of a sequential approach.

3.1 Placing the Relay Node

Consider a network with eight static traditional nodes $\{n_1,n_2,\ldots,n_8\}$ and a single relay node r_1 as shown in fig.1a. Here there are two active end-to-end multihop flows in the network with data rates λ_1 and λ_2.The set of one hop flows F in the network can be written as

F=$\{(n_1, n_2, \lambda_1), (n_2, n_3, \lambda_1), (n_3. n_4, \lambda_1), (n_4, n_5, \lambda_1), (n_1, n_6, \lambda_2), (n_6 ,n_7, \lambda_2), (n_7, n_8, \lambda_2)\}$

For a relay node to serve a flow the corresponding source-destination pair should be within the transmission range of the relay node. From the figure1.b. assuming that the flows $(n_3. n_4, \lambda_1)$ and (n_7, n_8, λ_2) are served by relay node, then the possible service sets of r_1 are $\{(n_3. n_4, \lambda_1), (n_7, n_8, \lambda_2)\},\{\{(n_3. n_4, \lambda_1)\}$ and $\{(n_7, n_8, \lambda_2)\}$.

Weights are assigned to the nodes depending on their contextual priority and residual energy. If the relay nodes were to serve more than two nodes, the optimal position of the relay node should be the weighted geometric centre of the source nodes in its service set which is given by

$$x_{r_i} = \frac{\sum_i w_i * x_{s_i}}{\sum_i w_i}$$

$$y_{r_i} = \frac{\sum_i w_i * y_{s_i}}{\sum_i w_i}$$

4 MOBILE NETWORK

In a mobile network, the nodes are highly dynamic and results in frequent topology changes. The location of traditional node continuously changes and the position of the relay node should be computed for each time instant. Therefore the operation of the network is modeled over fixed length time intervals called mobility epochs. The positioning and the movement of the relay nodes are based on the predicted changes in the network state over the duration of an epoch.

4.1 Solution for Min-Total

The first step is to determine the optimal service set of the relay and then compute the relay's optimal position. Also the communicating node pair of a flow in a service set should be within the range of the relay node throughout the epoch duration.

Cyclic dependency between the relay node's service set and movement of the relay node is addressed by the greedy heuristic algorithm in Fig.2 This algorithm is executed in a distributed fashion by every relay node in the network at the beginning of each epoch. As the first step, the relay node discards all the service requests whose corresponding node pair is not presently in its transmission range. It then adds the flow with the maximum weight in the request set to its service set. The trajectory of the relay node is defined using (9) based on the predicted positions of the nodes in its service set. The relay node then iteratively attempts to add more flows to its service set based on the descending order of their weights. Every time a new flow is added, the relay node redefines its trajectory and verifies that both the source and the destination nodes corresponding to the flows in its service set are predicted to be within its transmission range. If this constraint is not satisfied, then the newly added flow is discarded and the next flow in the request set is considered. A flow is also discarded if the gain in the total energy savings is negligible when compared to the energy savings under the previous service set. The algorithm terminates after all the flows in the service request queue have been processed once. Note that this heuristic evaluates just n of the 2n possible service sets and hence runs fast.

Input: $\mathbf{Q_i} = \{f_j = (s_j, d_j, \lambda_j), j=1\ldots k\}$

Output: $\mathbf{F_i}$, where $\mathbf{F_i} \subseteq \mathbf{Q_i}$

$\mathbf{Q_i \leftarrow Q_i - Q_i^*}$

for every $\mathbf{f_j} \in \mathbf{Q_i}$ **do**

Compute $P_j \leftarrow$ the power consumed f_j

end for

Sort $\mathbf{Q_i}$ in the descending order of the power consumption

$\mathbf{F_i \leftarrow \{f_1\}}$

Define the trajectory of R_i

$\overline{E_i} \leftarrow$ the energy savings by serving a single flow

for all j > 1 and $\mathbf{f_j} \in \mathbf{Q_i}$ **do**

$\mathbf{F_i \leftarrow F_i \cup \{f_j\}}$

if (s_j, d_j) are not predicted to be within the transmission range of R_i **then**

Continue

end if

$\overline{E_i} \leftarrow$ energy savings based on the service set $\overline{F_i}$

if $\frac{(\overline{E_i} - E_i)}{E_i} < \Delta_{th}$ **then**

Continue

else

$F_i \leftarrow \overline{F_i}$

$E_i \leftarrow \overline{E_i}$

end if

end for

Figure 2. Min-Total relay positioning algorithm for a mobile scenario

4.2 Solution for Min-Max

Unlike the Min-Total problem, we adopt a different approach to compute the min-max solution in a mobile setup. In the first step, the service set of the relay node consists of all the flows whose communicating node pairs are currently in the transmission range of the relay node. For every source node in its service set, the relay node then predicts their position at a fixed number of time instants over the course of an epoch. However, instead of computing a separate min-max solution for each of these time instants, we consider the node locations at all these instants as different points and compute a single min-max solution for the entire epoch. Based on this computed position for the relay node, we check to see if all the communicating node pairs are predicted to be within the transmission range of the relay node. If not, the flow with the lowest weight is removed from the service set and the process iterates until either all the nodes in the service set are predicted to be within the transmission range of the relay node or the service set consists of a single flow. Fig. 4 shows the min-max algorithm for a mobile scenario as described above. If the service set consists of a single flow, the relay is positioned as close as possible to the source node in order to save maximum energy in the source node.

5 RESULTS AND DISCUSSION

The Performance of Min-Max algorithm and Min-Total algorithm is evaluated.

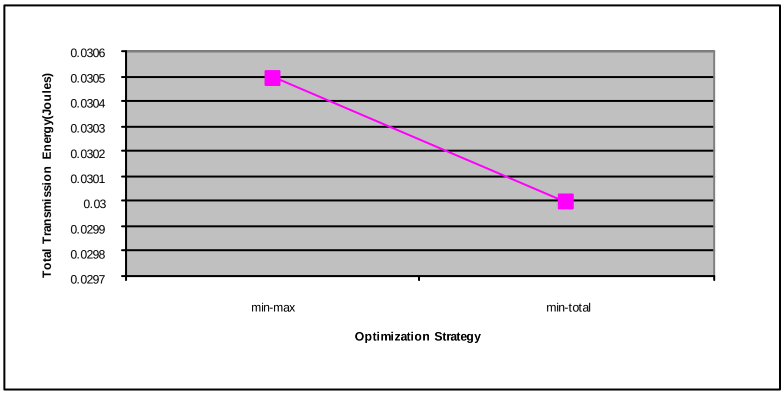

Figure 4. Min-Max Vs Min-Total

Input: $\mathbf{Q_i} = \{f_j = (s_j, d_j, \omega_j), j=1\ldots N_i\}$

Output: $\mathbf{F_i}$, where $\mathbf{F_i} \subseteq \mathbf{Q_i}$

X_{r_i} = (x_i, y_i)

$\mathbf{Q_i \leftarrow Q_i - Q_i^{\wedge}}$

$S_i \leftarrow \{\phi\}$

while $|Q_i| > 1$ **do**

for every $\mathbf{f_j} \in \mathbf{Q_i}$ **do**

(s_j^k, d_j^k) = Predict (s_j, d_j), k=1…m

$s_i \leftarrow s_i \cup \{(s_j^k, d_j^k, \omega_j)\}$

end for

Sort $\mathbf{Q_i}$ in the descending order of the power consumption

X $\leftarrow$ Compute – Min Max(s_i)

Dj $\leftarrow$ max $(\delta_{R_i, S_j}, \delta_{R_i, d_j})$

D $\leftarrow$ maxj, D_j

if D < Transmission Range of R_j, **then**

$\mathbf{F_i \leftarrow Q_i}$

$\mathbf{X_{R_i} \leftarrow X}$

stop

else

$Q_i \leftarrow Q_i - \{f_1\}$

end if

end while

$\mathbf{F_i \leftarrow f_1}$

Define the trajectory of R_i based on the predicted positions of the node pair (s_1, d_1)

Figure 2. Algorithm for Min-Max positioning of the relay node in a mobile network

From figure 4, it is found that, Min-Total algorithm results in better optimization of overall energy consumption. Min-Max algorithm results in optimization of maximum energy consumed by a node, but the overall energy consumption is more. Also, when the number of nodes supported by the relay node increases, the total transmission energy decreases as given in figure 5.

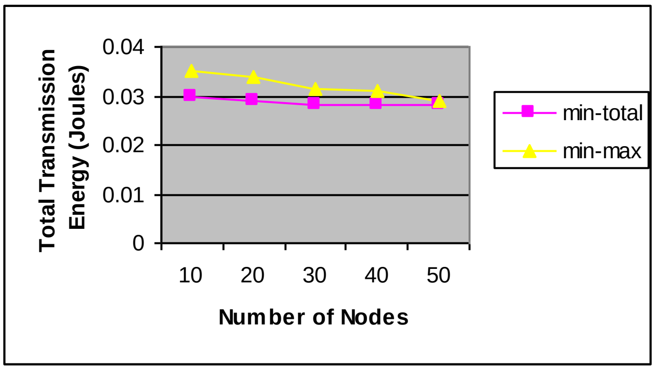

Figure 5. Total transmission energy by varying nodes

When the node density is high, both the algorithms have similar performance. The difference in their behavior is clearly evident when the node density is less. If the number of relay nodes is increased, the number of flows served by the relay node increases. Consequently the transmission energy consumed by the traditional node decreases resulting in performance gains. Also with longer epoch duration, the relay node supports limited flows resulting in decreasing performance gains.

6 CONCLUSION

In this paper, the problem of deploying relay nodes to conserve power in MANETs is studied. Two instances of the relay deployment problem, together with their solutions are presented. Instance 1, termed as Min-Total, minimizes the total energy consumed across all the traditional nodes during data transmission, while instance 2, termed as Min-Max, minimizes the maximum energy consumed by a traditional node during data transmission. The proposed framework minimizes the energy consumption at the traditional nodes while compromising on the energy resources at the relay nodes. Simulation results indicate that, deploying a small fraction of relay nodes using the proposed framework can not only result in significant energy savings but also improve the overall performance of the network. Combining both Min-total and Min-Max results in better energy savings.

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