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Deploying Relay Nodes with Controllable Mobility to Conserve Power in MANETs

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Abstract: ***In this paper, we consider the mobile ad hoc network (MANET) which consists of two types of mobile nodes called traditional and relay nodes. The traditional node has limited energy whereas the relay node has relatively abundant energy. The primary objective of this paper is to minimize the power consumption in the mobile ad hoc networks. The main idea behind the proposed relay node deployment framework is to efficiently deploy the relay nodes, so that the traditional nodes can utilize them as intermediate hops for communication. This improves the energy efficiency across the traditional node thereby maximizing the network life time. The proposed framework utilizes the mobility prediction scheme and works in tandem with the underlying MANET routing protocol called Maximum-Residual Energy Routing Protocol (MRERP). Two strategies of the relay deployment problem are presented together with the solutions, to achieve different goals. Strategy 1, termed Min-Total, aims to minimize the total energy consumed across all the traditional nodes during data transmission, while strategy 2, termed Minimum-Maximum, aims to minimize the maximum energy consumed by a traditional node during data transmission. Our solution enables the prioritization of individual nodes in the network based on residual energy profiles. Results indicate that the proposed framework results in significant energy savings, even when the relay nodes constitute a small fraction of the total nodes in the network.***

Keywords: controlled mobility, MANETs, relay nodes, energy efficiency, mobility prediction.

1. Introduction

In Mobile ad hoc networks (MANET), the mobile nodes communicate with each other by sending data flows either directly or through intermediate relay. The network topology and the paths of flows significantly affect the communication energy efficiency at individual nodes. Excessive or disproportionate energy consumption among nodes can lead to premature failure of the network. Traditionally, the mobility of nodes in the network is presumed to be beyond the control of any network protocol.

Typically, a node consumes much more power when it is actively transmitting data packets as compared to the packet reception and idle periods. Further, transmission over shorter distances consumes significantly less power when compared to long distance transmissions. The relay nodes can act as a intermediate nodes and help to maintain and improve the network connectivity. One way to minimize the power consumption is to have the sender utilize the relays as intermediate nodes and to transmit the data over shorter distance. The relay nodes can be appropriately positioned and moved so as to optimize the performance of the network with respect to a specific objective.

Relay nodes can prove to be useful in several scenarios. Consider the example of an emergency rescue operation being undertaken as a result of a terrorist hostage crisis. During the operation, different groups of rescue commandos need to communicate among themselves and possibly exchange their signals to successfully complete their mission goals. In such a scenario, one can employ fewer numbers of small, inexpensive mobile robots with abundant energy to relay the signals between the commando groups. Such relaying reduces the energy demands of the communication equipment carried by the commandos. This, in turn, reduces the baggage weight for the commandos, thereby increasing their mission utility.

The main goal of our research is to position and move such relay nodes in order to improve the energy efficiency across the traditional nodes.

Consider a heterogeneous network consisting of two kinds of mobile nodes, traditional MANET nodes with limited energy and a few controllable mobile relay nodes with relatively abundant energy resources.

Once deployed, a relay node estimates the movement patterns of the traditional nodes in its neighborhood using a mobility prediction scheme. It utilizes the predicted network state to adopt a mobility pattern similar to that of the traditional nodes and moves along with them serving as an intermediate hop for the data flows. The presence of such intermediate hops enables the traditional nodes to transmit data at reduced power and thus save energy.

We present two instances of the relay deployment problem, together with the solutions, to achieve different goals. Instance 1, termed Min-Total, aims to minimize the total energy consumed across all the traditional nodes during data transmission, while instance 2, termed Min-Max, aims to minimize the maximum energy consumed by a traditional node during data transmission. Our solutions also enable the prioritization of individual nodes in the network based on residual energy profiles and contextual significance.

The rest of the paper is organized as follows: We discuss about the related works in Section 2. We define the relay deployment problem in Section 3. We present the solution to the proposed problem for a static network in Section 4. We present the solution to the proposed problem for a mobile network in Section 5. In Section 6, we present the results from a detailed experimental analysis of the proposed framework and in Section 7 we present our conclusion.

2. Related Works

The idea of exploiting controlled node mobility in wireless ad hoc and sensor networks to achieve a given means has been explored by several researchers. Mobility controllable nodes have been used to improve network connectivity and communication in a sparse network using relay nodes with predefined trajectories [1] as well as general trajectories [2]. In [1], the authors utilize special nodes called as message ferries to carry messages between regular nodes across different network partitions. Controlled mobility has also been exploited to improve the coverage of a sensor network in [3], [4], where the authors propose mobility-assisted sensor deployment to detect coverage holes and efficiently relocate sensors in response to change in the network mission or overcome the loss of other nodes. In [5], the authors propose using relay nodes to exploit spatial diversity and mitigate the effects of path loss.

Most of the research work in the literature that utilizes mobility-assisted algorithms for improving energy efficiency in sensor networks with static nodes are based on the idea of using a mobile node either as a data sink [6], [8] or as a data relay [7], [9]. In [6], the authors explore a scheme to save power based on the predictable mobility of the data sink. This approach assumes that the sink node traverses the same path repeatedly and collects data from sensor nodes as and when they are within its transmission range. In [8], a similar approach is proposed where the exact speed profile followed along the path of a mobile sink is controllable. In [7], the authors propose a joint mobility and routing algorithm that assumes a dense static network with a fixed number of mobile relays. The relay architecture proposed in [10] finds the optimal node paths to conserve power as well as improve network coverage while considering the costs associated with communication and mobility. In [9], the authors use relay nodes moving in an uncontrolled fashion to transfer data from static sensors to a sink node. In addition to the above papers, other research activities on controlled mobility in ad hoc and sensor networks are reported in [11]. There has also been some work that aims to optimize the energy consumption in MANETs. Unified mobility control framework aims to achieve diverse configuration goals that can be tuned to ensure desirable network properties such as connectivity, coverage, and power efficiency. The framework optimally rearranges the intermediate nodes along the path of an existing flow so as to minimize the power consumed for transmission.

The framework proposed in this paper is different from the above in the sense that it considers a truly mobile scenario where the source and destination nodes move independently. The movement of the relay nodes is decided not only by the movement of the network nodes but also by the pattern of traffic flow in the network. Further, the objective of our framework is to minimize the energy consumption at the traditional nodes by leveraging on the energy resources at the relay nodes.

3. Relay Deployment Problem Formulation

The problem is formulated as the maximization of the minimum residual energy of nodes for each multicast and to minimize the overall energy consumption across the traditional node. Although the overall energy consumption in minimized, the energy consumption across the individual node may be uneven. So we have to minimize the energy consumed by the traditional nodes. In terms of energy consumption, a data flow occurring between two end nodes over a multihop path can be viewed as a sequence of one hop flows between adjacent nodes along the multihop path.

3.1 Instances of Relay Positioning Problem

Let S_T be the set of traditional nodes and S_R be the set of controllable mobile relay nodes in the network. Let IF be the set of all one-hop flows in the network. Specifically, the set IF consists of tuples $f_i = (s_i, d_i, \lambda_i)$, i=1…k, where each f_i represents a flow between a communicating node pair (s_i, d_i), s_i, $d_i \in S_T$ with a data rate of λ_i. If a node transmits to another node at distance d away, taking into account the loss rate of the link and minimizing the expected energy cost to send one message, we have the transmission power function $P_T(\delta_{sd})$. The energy consumed for data transmission by a flow f_i per unit time at node s_i is given by

$$E_i(\lambda, \delta) = \lambda_i . P_T(\delta_{sd}) \qquad (1)$$

where δ_{sd} denotes the distance between the two nodes s_i and d_i, and $P_T(\delta_{sd})$ is the energy needed for transmitting one bit of data between the nodes. The energy function $P_T()$ is usually given by $P_T(\delta_{sd})= a+b\delta^{\alpha}_{sd}$, where $\alpha \geq 2$, and a and b are parameters whose values depend on the characteristics. Based on the definition, the two instances of the relay positioning problem is being defined.

3.1.1 Minimize Total Energy: Min-Total

The objective of this strategy is to place a relay node in such a way as to minimize the overall energy consumption across the traditional nodes in its service set. The total energy consumed per unit time for data transmission at the traditional nodes in the absence of any relay nodes is given by

$$E_{tot}(X_T, IF) = \sum_{f_i \in IF} E_i(\lambda, \delta) \qquad (2)$$

where X_T is the vector denoting the locations of the traditional nodes at any given time instant. For any X_R and IF_R. X_R denotes the location of the relay nodes, X_T—the location of the traditional nodes, IF—the set of flows in the network, and IF_R—the combined service set of the relay nodes. Out of these, the controllable quantities are X_R and IF_R. Thus, with these preliminaries, we define the relay positioning problem for minimizing the total energy consumed as:

Min-Total. Given a network with $|S_T|$ traditional nodes and $|S_R|$ relay nodes, find the optimal relay node position X^*_R and the optimal service set IF^*_R such that

$$E_{tot}(X_T, X^*_R, IF, IF^*_R) \leq E_{tot}(X_T, X_R, IF, IF_R)$$

3.1.2 Minimize Maximum Energy: Min-Max

One of the drawbacks with the Min-Total formulation is that although the overall energy consumption is minimized, the energy consumption across individual nodes may be rather uneven. To address this issue, we formulate a different strategy where the objective is to minimize the maximum transmission energy consumed across the traditional nodes in the network. Given the service set IF_R of a relay node $Rj \in SR$, the maximum energy consumed by a traditional node in IF_R is given by

$$E_{max}(X_R, IF_R) = \max\{E_i(\lambda, \delta)\}$$

The objective of this formulation is to find the optimal position of every relay node $R_j \in S_R$ such that the resulting configuration minimizes E_{max} for the service set IF_R. Clearly, this also requires that one must define and then compute the best possible service set for every relay node. Based on these preliminaries, we define the relay positioning problem for minimizing the maximum energy consumed in a traditional node as:

Minimum-Maximum. Given a network with $|S_T|$ traditional nodes and $|S_R|$ relay nodes, find the optimal service set IF^*_{Rj} for every relay node $R_j \in S_R$ and for this service set, find the optimal position X^*_{Rj} such that

$$E^j_{max}(X^*_{Rj}, IF^*_{Rj}) \leq E^j_{max}(X_{Rj}, IF^*_{Rj})$$

3.2 Incorporating Node Weight

The problem definitions described so far take into account only the energy consumption at individual nodes based on the existing data flows. In other words, solutions to both the Min-Total and Min-Max problems would favor the source nodes with higher data flow rates. However, it is also desirable that the relay nodes be deployed closer to source nodes with low residual energy even when the data rates of the existing flows through these nodes are small. Further, the network may contain certain critical nodes that are essential for the successful operation of the underlying application. In such scenarios, it is important that the relay nodes be deployed so that the resulting configuration prolongs the lifetime of such nodes while still achieving the required energy optimization.

We incorporate these factors in the problem formulation by assigning a weight w_i to each flow $f_i \in IF_{Rj}$. The weight w_i represents the priority assigned to the flow f_i and is derived from the corresponding source node. Let ϵ_i and p_i denote the residual energy and contextual priority of the source node s_i corresponding to the flow f_i. The weight w_i is then given by

$$w_i = z_1 * \lambda_i + z_2 * p_i \quad (3)$$

where z_1 and z_2 are the relative weights assigned to the residual energy and contextual priority, respectively, by the network operator.

3.3 Toward a solution

It is evident from the definitions of the relay deployment problems that the movement and positioning of the relay nodes is primarily contingent upon the position of the traditional nodes and the set of active flows between them. This is called as network state information and the relay node dynamics is shown in figure 1. Given this network state information, arriving at the solutions for the two relay deployment problem instances is effectively a two-step process:

1) Decide the optimal service set for every relay node.
2) Then compute the optimal position of every relay node as per the objective function based on its service set.

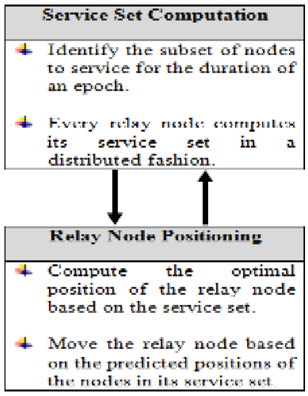

Figure 1: Relay Node Dynamics

The service set computation for a relay node utilizes only the local network state information in the neighbourhood of the relay node. The flow chart for service set computation is shown in Figure 2. The global state information is not used for the following reasons:

1) Obtaining global information about location and data flows in a mobile wireless network can be quite expensive in terms of energy which negates the very goal of using relay nodes and
2) Even if global information is available, it may not always be possible to put the information to good use. For example, the global state may indicate that a relay node could serve better if it moves to a different neighbourhood. By the time, the relay node moves to that neighbourhood, the state there may change undermining the need for the relay node.

Flow can be added to a relay's service set as long as the communicating node pair corresponding to that flow is in the range of the relay node. In a mobile setting, this requirement translates to making sure that the communicating nodes continue to remain in the range of the relay node throughout the epoch duration. First the optimal service set of a relay is determined, and then the relay's optimal location is computed based on the service set for different epoch instances.

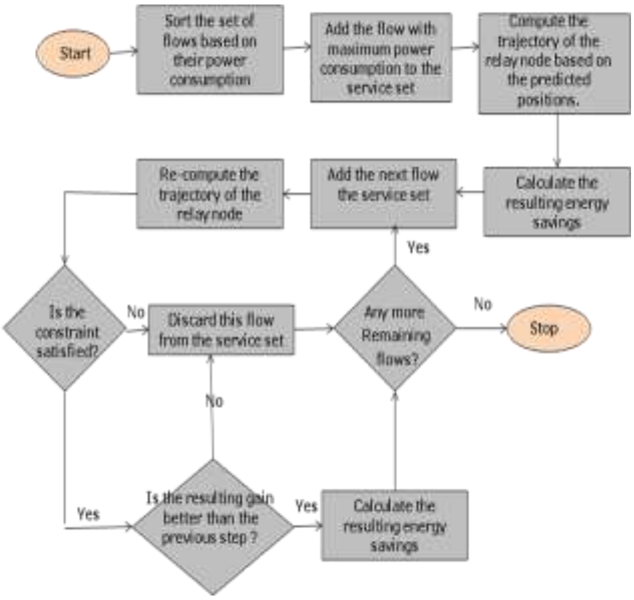

Figure 2: Flow chart for service set computation

4. Solution For A Static Network

Let us consider a simple scenario of an ad hoc network where the nodes are static with a fixed set of flows between them. Figure 3 illustrate the basic idea behind the solutions. Consider a network of six static traditional nodes $\{N_1,..., N_6\}$ and a single relay node R_1. Suppose that there are two active end-to-end multihop flows in the network with data rates λ_1 and λ_2 that traverse through multihop paths as shown. In the scope of our problem definitions, this translates to five pairs of communicating nodes representing the single-hop links along the flow paths. The set of one-hop flows IF in the network can then be written as

$$IF = \{(N_1,N_2, \lambda_1),(N_2,N_3, \lambda_1),(N_2,N_5, \lambda_2), (N_3,N_4, \lambda_1), (N_5,N_6, \lambda_2)\}$$

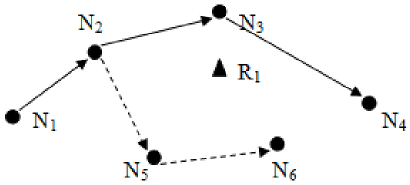

Figure 3: Data flows without using a relay node.

Suppose that the relay node R_1 is deployed in the neighborhood of nodes N_3, N_4, N_5, and N_6. Since the service set for a relay node is determined based just on the local neighborhood information, (N_3, N_4, λ_1) and (N_5, N_6, λ_2) are possible candidate flows that can be served by R_1. For obvious reasons, it is required that for a flow to be served by a relay node, the corresponding source-destination node pair should lie within the transmission range of the relay node. If we assume that the flow (N_3, N_4, λ_1) and (N_5, N_6, λ_2) satisfy this criteria , then the possible service set of R_1 are

$$\{(N_3, N_4, \lambda_1) \text{ and } (N_5, N_6, \lambda_2)\}$$

4.1 Solution For Min-Total

Consider the service set $IF^1_{R1}= \{(N_3, N_4, \lambda_1), (N_5, N_6, \lambda_2)\}$.For this service set, it can be shown that the optimal position (x_{R1}, y_{R1}) of the relay node R_1 is given by

$$x_{R_1} = \frac{w_1 x_{N_3} + w_2 x_{N_5}}{w_1 + w_2}$$

$$y_{R_1} = \frac{w_1 y_{N_3} + w_2 y_{N_5}}{w_1 + w_2}$$

where (x_{N_3}, y_{N_3}) and (x_{N_4}, y_{N_4}) represent the position coordinates of the nodes N_3 and N_4, respectively, and $w_i=w_i * \lambda_i$.

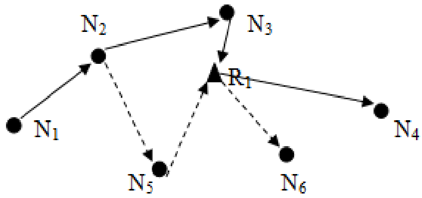

Figure 4: Data flows after deploying the relay node.

If $w_1>w_2$, R_1 should be deployed on a straight line joining the two source nodes N_3 and N_5, closer to N_3 to an extent determined by their node weights, as shown in Figure 4. If the relay nodes were to serve more than two nodes, it can be argued that the optimal position of the relay node should be the weighted geometric center of the source nodes in its service set for cases where the exponent α in the power function P_T equals two. For scenarios where $\alpha > 2$, it is challenging to obtain a closed-form expression for the optimal relay position. Ideally speaking, the energy savings achieved when the relay is optimally placed in all the three service sets should be estimated and the set that gives the maximum power savings should actually be taken up for service.

4.2 Solution for Minimum-Maximum

Minimizing the power consumed during transmission is same as minimizing the distance between the relay node and traditional node. The min-max solution reduces to place the relay node in the center of a circle that minimally encloses all the traditional nodes. As indicated earlier, $E^j_i(\lambda, \delta)$ is given by $E^j_i(\lambda, \delta) = \lambda_i.P_T(\delta_{siRi})$, where δ_{siRi} represents the distance between the relay nodes R_j and the source node s_i. We get,

$$E^j_{max}(X_{Rj}, IF_{Rj}) = \max w_i.P_T(\delta_{siRi}) \quad (4)$$

where $w_i=w_i * \delta_i$. In other words, for a given service set, the min-max formulation reduces to the weighted minimum circle problem. Any strategy devised for solving the weighted minimum circle problem can be applied to obtain the optimal relay node coordinates under the Min-Max problem too.

5. Solution For A Mobile Network

In a mobile network, the network state is highly dynamic due to the mobility of the traditional nodes. Extending the relay positioning solutions obtained for a static network to a mobile network is nontrivial due to the following reasons:

1. The location of the traditional nodes varies continuously with time. Consequently, the optimal position of a relay node should be computed for each time instant. In other words, this translates to defining the optimal trajectory for a relay node based on the movement of the traditional nodes in its service set.
2. The mobility of the nodes leads to frequent changes to the route traversed by a data flow which may further add to the dynamics in the set of one-hop flows in the network.
3. The set of end-to-end flows in the network could also be time-varying based on the requirement of the underlying application.

5.1 Mobility Epochs

In order to extend the solutions obtained for a static network to a mobile network, a relay deployment framework is being proposed that models the operation of the network over fixed length time intervals called mobility epochs. Decisions pertaining to the positioning and movement of the relay nodes are based on the predicted changes in the network state over the duration of an epoch. The mobility of the nodes is being predicted during an epoch using a mobility prediction scheme and use the predicted state to manipulate the relays. Of course, there can be errors in prediction which can affect the efficacy of the relay deployment.

In developing a solution, for simplicity, the set of active flows is assumed in the network which remains constant over the duration of an epoch. This is reasonably valid in networks with short epoch durations and long-lived flows. The decisions pertaining to the positioning of the relay node could result in a suboptimal solution if flows terminate or if new flows originate during the course of an epoch, which can happen in a generic network. Finding an optimal value for the duration of a mobility epoch is often nontrivial, as we have to consider the extent of dynamics in the network and the frequency of topology changes.

It is quite possible that the calculated epoch duration could result in a solution which may not keep abreast with the changes in the network. In general, an ideal solution should have the flexibility to have variable length epoch durations with the number of relay nodes deployed in each epoch being decided by the network state that exists then.

5.2 Mobility Prediction

In a mobile network, relay node deployment translates to defining the trajectory for the relay node such that it always remains at the optimal position relative to the positions of the nodes in its service set. A trivial way to achieve this could be to have the traditional nodes send location updates to the relay node at every time instant throughout the duration of an epoch. The relay node would then constantly compute its optimal location coordinates based on these location updates and position itself accordingly. Though this approach would result in an optimal trajectory for the relay node, it is clearly not feasible due to the communication overheads involved.

To address this issue, the proposed framework utilizes mobility prediction algorithms to estimate the movement patterns of the mobile nodes. Once the relay node finalizes its service set, it computes its optimal position coordinates at different time instants over the duration of an epoch using the predicted location of the source nodes corresponding to the flows in its service set. Based on these predicted position coordinates, the relay node then defines its trajectory for the duration of the epoch.

5.3 Flow Information Aggregation Mechanism

The mobility of the nodes coupled with the characteristics of the underlying application often result in a varying number of data flows in the network where a certain number of flows may be short lived whereas certain others may remain active over a longer duration. In order to facilitate the exchange of such flow-specific information between the relay nodes and the traditional nodes, we utilize three control messages: Hello, Service Request and Service Response.

The HELLO message, which is broadcast by all nodes in the network once every epoch, serves two different purposes. First, the HELLO nodes are used to exchange location and movement information across neighbouring nodes. In addition, the HELLO message broadcast by a relay node also acts as a service advertisement message that informs the traditional nodes in its vicinity of the availability of a relay. Any traditional node that wishes to solicit the services of the relay node sends an SREQ message back to the relay node in response to the HELLO message. The SREQ message consists of information regarding all the data flows that the node is actively transmitting. If a traditional node receives HELLO messages from more than one relay node, it sends an SREQ message to the closest relay node in its neighbourhood.

The relay node collects all the service requests from the traditional nodes during an epoch and utilizes the aggregated flow information along with the location and movement information obtained from the HELLO messages, to compute its service set for the following epoch using the algorithms described in 5.4 and 5.5. Once the relay node finalizes its service set for the duration of an epoch, it sends an SREP message to all the source nodes in its service set which completes the handshake between the nodes. The SREP message also contains information pertaining to the movement pattern of the relay node for the duration of that epoch. The traditional nodes utilize this information to estimate their distance to the relay node in order to appropriately set the transmit power when communicating with the relay node.

5.4 Min-Total Solution For A Mobile Network

The solution for Min-Total in a truly mobile network revolves around first determining the optimal service set of a relay, and then computing the relay's optimal location based on this service set for different epoch instances. A flow can be added to a relay's service set as long as the communicating node pair corresponding to that flow is in the range of the relay node.

In a mobile setting, this requirement translates to making sure that the communicating nodes continue to remain in the range of the relay node throughout the epoch duration. This constraint can be verified by examining the relative distance between the predicted position of the relay node and the communicating node pair at various time instants over epoch duration. However, note that the movement of the relay node can be predicted only when its service set has been finalized. This creates a cyclic dependency wherein computing a relay node's service set depends on the movement of the relay node, which, in turn, depends on the service set of the relay node.

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.

5.5 Minimum-Maximum Solution For A Mobile Network

In order to find the optimal service sets and the optimal trajectory under the Min-Max formulation, then a similar algorithm is formulated as done in Min-Total, i.e., order the flows based on their weight and include each serviceable flow one by one as long as the energy savings increase. The trajectory of the relay node would then be the locus of the optimal locations for the resulting service set at various instances in an epoch.

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 using the algorithm.

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. 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.

6. Implementation Methodology

This section discusses about the implementation methodology of the proposed system and the greedy heuristic algorithm called Min-Total and the Min-Max algorithm. The main objective is to minimize the power consumption in MANETs and to efficiently deploy the relay nodes in the network such that the traditional nodes can utilize them as intermediate hops for communication. The energy efficiency across the traditional nodes is also improved.

6.1 Steps Involved

Step 1: Creation of heterogeneous mobile ad hoc network with two kinds of mobile nodes Traditional node Relay nodes.
Step 2: The traditional nodes are assigned with limited energy and relay nodes are assigned with abundant energy.
Step 3: The source node sends the request message to the destination.
Step 4: Based on the request, the possible service set is calculated.
Step 5: For every flow in the service set calculate the power and sort the flow in the descending order of power consumption.
Step 6: The flow with best energy consumption is determined and the power consumption is calculated first, without deploying the relay node. Then the relay node is deployed based on the prediction schema and service set is computed based on Min-Total and Min-Max algorithm.
Step 7: Energy calculation is done after deploying the relay nodes.
Step 8: The performance comparison is done with the existing method (without relay) and the proposed algorithm (Min-Total and Min Max). And it is inferred that the amount of energy consumed after deploying relay node is lesser than without applying relay node.

6.2 Greedy Heuristic Algorithm: Min-Total

A greedy heuristic algorithm called Min-Total relay positioning algorithm is proposed that iterates over different possible service sets of a relay node and jointly determines the relay node's service set and trajectory. 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 and defines its trajectory assuming that this is the only flow that the relay would serve during the epoch. The trajectory of the relay node is defined based on the predicted positions of the nodes in its service set. Even though the relay node received the SREQ from the source, it is possible that the destination may not presently be in the relay node's transmission range.

6.3 Minimum-Maximum Algorithm

In Minimum-Maximum algorithm, order the flows based on their weight and include each serviceable flow one by one as long as the energy savings increase. The trajectory of the relay node would then be the locus of the optimal locations for the resulting service set at various instances in an epoch. The min-max algorithm for a mobile scenario as described below.

Hence, the power consumption in MANET is minimized by efficiently deploying the relay nodes in the network. And the relay deployment algorithms which are proposed will achieve two different optimization strategies - network-wide energy minimization and individual node fairness and also it enables the prioritization of individual nodes in the network based on residual energy profiles and contextual significance.

6.4 Results and discussion

The heterogeneous mobile ad hoc network is created with two types of mobile nodes. They are traditional nodes and relay nodes. The traditional nodes are assigned with limited energy whereas the relay nodes are assigned with abundant energy. The total numbers of traditional nodes added to the mobile ad hoc network are 65. The traditional nodes are assigned with limited energy. The total numbers of relay nodes added to the mobile ad hoc network are 7. The relay nodes are assigned with abundant energy.

The network was portioned into two groups containing the traditional node and the relay node. All nodes in the network were assigned an equal contextual weight with each node having a similar initial battery power. The source node sends the request message to the destination nodes. For every flow in the service set calculate the power and sort the flow in the descending order of power consumption. The best energy efficient path is determined from each service set to reach the destination nodes. The power consumption for each flow is calculated, first without deploying the relay node. Then the relay node is deployed based on the prediction schema and service set is computed based on Min-Total and Min-Max algorithm.

6.5 Performance Comparison

The proposed relay deployment framework is compared with the existing algorithm (i.e., without deploying relay node). The energy consumed by nodes in the mobile ad hoc network without deploying the relay node is compared with the Min-Total and Min-Max algorithm. The power consumption is minimized when the Min-Total and Min-Max algorithm is used. Table 1 shows the performance comparison in energy consumption between the proposed and existing work.

Table 1 shows the performance comparison based on energy consumption.

Table 1:Performance Comparison

Destination Node	*Without Relay (Joules)*	*Min-Total (Joules)*	*Min-Max (Joules)*
N52	301.91	266.01	45.378
N38	269.18	265.18	33.616
N7	292.31	261.214	43.370
N8	271.08	259.06	45.366
N3	211.84	206.84	32.763

In Figure 5, the bar chart shows the comparison between the proposed Min-Total and the existing work (without relay nodes).

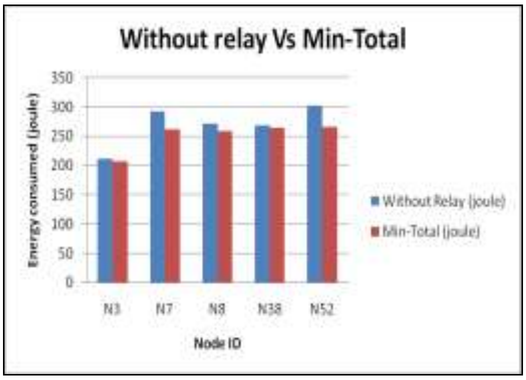

Figure 5: Without relay nodes Vs Min-Total

In Figure 6, the bar chart shows the comparison between the proposed Min-Max and the existing work (without relay).

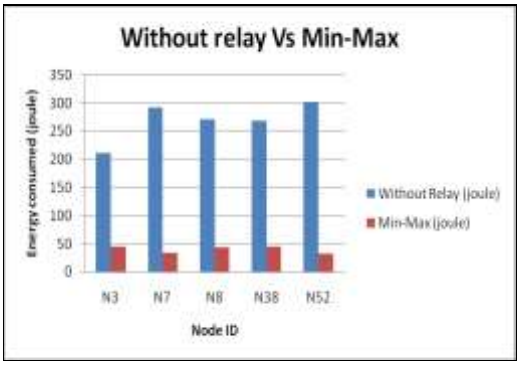

Figure 6: Without relay Vs Min-Max

Thus the proposed framework minimizes the power consumption in the mobile ad hoc networks. And the relay nodes are efficiently deployed in the network such that traditional nodes can utilize them as intermediate hops for communication and the energy efficiency across the traditional nodes is improved.

7. Conclusion and Future Work

Thus the proposed relay deployment framework utilizes the mobility prediction scheme and works in tandem with the underlying MANET routing protocol. And the relay nodes are deployed efficiently in the network such that the traditional nodes can utilize them as intermediate hops for communication and the energy efficiency across the traditional nodes is improved. Hence the power consumption is minimized in the mobile ad hoc networks and the network life time is increased. As the future work, the objective function can be modified as maximizing the network connectivity and the contextual prioritization can be taken into consideration.

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