A Predetermined Energy Based Efficient Routing Mechanism for MANET

Maddhi Sunitha
Department of Computer Science and Engg, CVR College of Engineering Hyderbad, Telangana-501510, India.

Podili V.S.Srinivas
Department of Computer Science and Engg, J.B Institute of Engineering and Technology, Hyderabad, Telangana-500075, India.

Temberveni Venugopal
Department of Computer Science and Engg, JNTUHCES, Sultanpur, Medak, Telangana-502293, India.

Abstract
An ad hoc network construction suffers due to many technical barriers such as limited energy consumption, unreliable wireless link, and dynamic network topology which is a challenging issue. There is an important link trade-off among the very unreliable network maintenance and energy protection for users with small battery power. In this paper, we focus on a Predetermined Energy Based Efficient Routing (PEBER) Mechanism for MANET. It utilizes a "power saving mechanism" (PSM) through rebroadcasting iteration control and determine the required energy considering the path distance and minimum energy required between nodes to decrease the routing overhead and energy in node scalability and mobility scenario. The PEBER controls the packet loss caused due to node mobility and link failure maintaining the energy efficiency in a reactive routing protocol. The simulation results demonstrates an advancement indication of energy saving than the existing energy saving routing protocols.

Keywords: Energy efficient routing, Power Saving, Energy predetermine, MANET
I. INTRODUCTION
Routing protocols should be able to take action promptly to link breakdowns and at the same moment, it can decrease unavoidable routing overhead to preserve energy. From this point of view, power aware routing necessitates being believed extensively. There have been many studies on energy conservation which are being explored [1], [3], [8]. Much of this work focuses on "packet transmission", "link layer", and "routing protocols" in the network layer. However, the current power saving method does not maintain the device to operate long enough. Also, in some application scenarios, such as sensor networks and dynamic ad hoc networks, it may not be appropriate to change the battery. Therefore, energy-saving systems in wireless ad hoc network are exceptionally essential. Energy costs in relation to the energy consumption of all mobile devices in communications is a substantial part which has become smaller and required a more efficient solution. In the subsequent sections we converse in relation to the brief descriptions of the generally relevant energy saving routing protocols to illustrate our motivation [20], [25], [28].

Because MANET does not rely on a pre-configured infrastructure, it can be deployed in a non-infrastructure location. This is useful in disaster recovery situations where communication networks are installed quickly when needed, and where there is a non-existent or compromised communication infrastructure [2], [3]. However, specific minimum link level power control from source to destination cannot guarantee that end-to-end energy consumption will be minimum. Many energy-efficient routing protocols have been recommended to save energy in literature [1], [2], [3], [4], [5], [7], [8]. All of these suggestions focus on optimizing and conserving as much power as possible. However, due to limited propagation and mobility, MANET introduces frequent link errors and high overhead using a large amount of additional power to achieve throughput.

Most of the existing link cost model suggestions ignore the actual energy requirements during routing because they ignore the additional energy utilization suitable to exchange control packets at the data link layer. For example, in an 802.11 network model, relay and control packets (CP) are sent at the highest power level. The effect of mobility is frequent link loss and affects routing data packet loss, which in turn results in a high number of CP exchanges among the transitional node and the source node. This results in routing overhead and additional power loss.

In this paper, we present a predetermination energy based efficient routing (PEBER) support on energy efficient route discovery using PSM mechanism between source to destination and probably identifying the predetermined energy required in a path for data routing. PSM mechanism [5] identifies the most power sufficient node during route discovery process and a predetermined is through number of hops, total distance and total probable minimum energy are required in a path.

The rest of the paper planned as follows. Section-II, focus on the related works in related to the energy efficient routing. Section-III, discuss an energy efficient routing model for the wireless network. Section-IV described the proposed predetermined
energy based efficient routing. Section-V presents the performance evaluation results analysis and Section-VI presents the conclusion of the paper.

II. RELATED WORK

In a hop based wireless networks, a number of energy-aware routing protocols in a multi-path has been proposed to further increase energy efficiency. Several geographically local routing protocol using only local information to make decisions in a smarter way and to decrease the routing overhead is proposed. However, the energy efficiency of the recommended paths using local routing methods cannot be guaranteed.

To overcome the disadvantages of the current methods, that did study the popular routing method with high energy efficiency in ad hoc wireless networks. These protocols are used in dissimilar approaches to achieve energy efficiency or balance of the battery consumption. However, most of these protocols are trying to find some mechanisms for network level to avoid flooding and unnecessary packet forwarding, but the main disadvantage of most of these temporary routing protocols is that the data is not provided to convey routing congestion and the quality of the routing path. As in the past decade, several energy-efficient routing protocols were proposed and it was asked to find the best solution out of it. As it is very difficult to constrain the technology and research and excavation optimal solution, many developments with significant modifications have been made to modify the DSR as the efficient routing protocol and serve as effective routing protocols as other protocols. So the next sections we discussed a few important routing protocols that are made after making some changes to the traditional protocol DSR.

A. Energy Conservation in MANET

The main intuition of this paper is that nodes and network lifetime is increased by conserving power and carefully sharing the cost of packet routing. Therefore, this section presents some power-aware metrics that provide an energy-efficient path.

- **Minimum Energy consumption**: This is one of the apparent metrics that reflect our intuition about energy conservation. Assume that some packet \( p \) navigate through nodes \( n_1, \ldots, n_v \) where \( n_1 \) is the source and \( n_v \) the destination. Let, \( C(x, y) \) indicates the energy addicted whilst sending and acceptance one packet commencing from \( x \) to \( y \). Then the energy consumed for every one packet \( p \) communication is \( E_n \),

\[
E_n = \sum_{d=1}^{v-1} C(n_d, n_{d+1})
\]

So the purpose of this metric is to uncover the minimum \( E_n \) needed to transport packet \( p \) in the path from \( n_d \) to \( n_{d+1} \). It is easy to see if this metric helps to choose the minimum energy consumed per packet for routing. In fact, it is interesting to note that for a
minimum load, the path chosen when using this metric is the same as the path selected by the shortest hop routing. This is not an unexpected observation because, if we assume that $C(x, y) = C (x constant), \forall(x, y) \in V,$ where $V$ is the collection of all node edges, then the power consumed is $(v-1)C$. To minimize this value, we need to minimize $v$, which will be equivalent to finding the shortest path.

In some cases, this may change the way chosen by the shortest hop routing path selected when using the metric. Thus, if the interests of one or more nodes of the shortest-path hop, hop over a fixed quantity of energy consumed to transmit a packet. But this metric has one serious drawback, some low power nodes might die and significantly tend to change its energy profiles.

**B. Energy Efficient Routing**

Many energy-efficient routing protocols [14], [15], [16], [17], [18], [19], [20] have recently been proposed using a variety of technologies, given that energy is an inadequate resource that restricts the generation of wireless networks.

Classical routing algorithms are capable of being accustomed to non-classical criteria of energy-related metrics such as delay or hop distance. The strength to communicate the proposed energy awareness link metric is defined as a function of many as in [14], [27], or a node lifetime function [20]. However, the minimum strength, absence of a directive [23], [24] and selecting routes centralized algorithm for reducing global energy consumption. In this paper, we focus on localized routing, therefore, it considers that we only work with energy efficient mechanism for localized routing and explain how to conserve energy when considering local routing decisions.

Kuruvila barrel. [13] proposed a new power-aware of local power-path routing, which selects the current node's neighbors, to decrease the proportion of energy consumption and the distance travelled to the destination node. It is a first localized method that supports on the association involving the cost of development. The author also suggests several versions and conducts extensive simulations. Stojmenovic [16] generalized this concept to the cost of advancement and provided a good investigation of the general routing framework and numerous comparable routing methods. The use of energy mileage in routing methods to limit energy effectiveness has been motivated by these studies.

Stojmenovic et al.[16] proposed a power-aware localization that combines a cost metric support on the battery level at the node and a power metric support on the transmit power associated with the inter-node distance. They demonstrate the loop less nature of their methods and demonstrate efficiency through experiments. In [6] they combined the above methods with face routing to ensure efficient delivery. However, it does not guarantee energy efficiency theoretically for all methods.

Melodia et al. [17] on the basis of local knowledge of the topology, each node chooses the way to reduce-power, in sensor networks, where the proposed scheme is partial topology knowledge forwarding. There is certain range for each node in the topology and each node gathers information of its neighbourhood using Neighbor Discovery
Protocol. They can reduce the power consumption of the network of choice for a range of linear programming to derive the formula. Because it is not really a feasible solution to the problem of linear programming, they can be connected to a distributed protocol recommended topology knowledge.

Seada et al. [22] consider the transmission of power, but also the reliability of each link is an energy-aware routing scheme proposed by the greedy. Their research focuses on routing on lossy links sensor networks. They are multiplying, improving packet reception rate and distance, a new local for greedy routing metric is used. They offer a solution to a significant loss in consideration of the transmission power sensor networks that have shown transmission and energy efficiency.

C. LEARN: Localized Energy-Aware Restricted Neighborhood Routing

The mechanism of LEARN [4] describe the path which can be found successfully, it tries to ensure energy efficiency of the path. In theory, LEARN routing studies important transport radius in any network that can ensure that routes to the source and destination pairs are almost and gradually found. In multi-hop wireless networks these devices possibly will be improved when designing protocols for the wireless devices are generally powered by batteries and because of the limited time computing capabilities, energy conservation, and the stretch will be the two important issues.

We are carefully selecting forwarding neighbor routing decisions using only local information to be energy efficient and highly scalable routing protocols for multihop wireless networks to focus on design. As far as possible in LEARN, the node chooses its neighbors in the restricted neighborhood which defined by parameter α, and among the principal energy mileage (i.e., travel distance per consumed unit energy) as the next hop node. In its theory, LEARN proved to be energy efficient. That is in LEARN, routing node on the path from the source to the target node, found a way to use the power that one finds inside the stable factor. We extend this approach in PEBER for energy efficient data routing on post route discovery process.

The routing protocol uses packet forwarding path through the source and destination which stores the full path it uses. Thus, in DSR the destination knows complete hop-by-hop routing [21], [24]. With DSR routing packets makes no loops. Intermediate nodes need for up-to-date routing information to avoid, in addition, nodes can cache the data packets by exaggerating routes. The main advantage of DSR is that it saves bandwidth and reduce power consumption. In addition, corrupt links to the route, the source node, and the valid route can check the cache. However, AODV makes use of conventional routing tables and upholds one path per destination.

Because it is a single-path protocol, we are required to describe an innovative route search each time the route from source to destination does not succeeds. AODV exploit the target sequence number to prevent routing sequences and establish the up-to-date nature of the routing information. In addition, AODV uses a timer-based route expiration system to immediately remove old routes. If a lower value is selected for a timeout, a valid route may be unnecessarily disposed of. Frequent topology transforms
require frequent path traversal, which may be inefficient in relation to the overhead that path search flooding can cause significant energy consumption. For the above reasons, choose a DSR-based mechanism for PEBER. The mechanism of PEBER has illustrated it features in the next section.

III. PREDETERMINED ENERGY BASED EFFICIENCY ROUTING

The "Dynamic Source Routing Protocol" (DSR) for MANET [21] was an excellent routing protocol that acts upon over and over again enhanced than erstwhile routing protocols. However, the performance, energy consumption at each node of the network, energy consumption per successful packet transmission [20], energy consumption of node due to various overheads. DSR protocol does not consider energy at all as a parameter. In addition, MANET is very sensitive to power-related problems and energy consumption driven by batteries using limited sources and therefore requires a routing protocol that considers energy parameters and aims to extend the life of the network. A power saving mechanism (PSM) through rebroadcasting iteration control in mobile ad hoc network is proposed in [5]. We extend PSM mechanism for route discovery process and integrate the LEARN [4] routing mechanism to build PEBER routing mechanism.

A. Route Discovery using PSM Mechanism

Route Discovery (RD) is the main activity that MANET performs to find the destination node. To do this, it broadcasts an RREQ message to each node in its transmission range, and each receiving node broadcasts the message again for the first time, and this broadcast continues until it finds the destination node in the network, which is a common broadcasting mechanism. However, this rebroadcast mechanism causes significant power loss due to redundant transmission and reception on the network. Therefore, the problem of conserving power loss by reducing the rebroadcasting activity is the main research topic of MANET. We assume a cooperative network model[11],[12] as shown in Fig. 1 having a source node (S), few intermediate nodes (I) and a destination node (D) and each node equipped with unidirectional relaying antennas. Lets represent all set of nodes in the network as $Z$, i.e., $|Z| = M$. Each network node $m \in Z$ has a unique identification number represented as, $id(m)$ and they are scattered in a two-dimensional space. We also assume two nodes $x \in Z$ and $y \in Z$ in the space can be connected if their transmission range, $|xy| \leq R$, where $R$ represents nodes transmission ranges. Thus, the network graph can be represented as, $G(Z, R)$, which will be typical ad hoc network communication model.
We compute the power consumption of the broadcasting support on the above network model graph, $G(Z,R)$ and Fig.1 representation. Let's assume a source node $S$, has $k$-nodes in his communication range $R$ and each of these node have an arbitrary status power level. We suppose that all the nodes consumes a constant power for the transmission as, $P_{TX}$, receiving as, $P_{RX}$ and for the computation as $P_{PR}$. To understand the baseline power consumption $P$, we first compute a direct transmission power between a source $S$ and destination $D$ as,

$$P_{(S,D)} = (P_{TX} + P_{RX} + P_{PR})^2 \tag{1}$$

The power, $P_{(S,D)}$ is the minimum power required for a node to communicate with a direct node in its range. So, for the $k$-nodes, $S$ performs one transmission but it receives $k$ replies and $k$ times it needs to process the message it receives, and the total power consumption $P_{(S \rightarrow k(1,n))}$, can be computed as,
\[ P_{(S \rightarrow k, 1,n)} = \sum (P_{TX} + k(P_{RX} + P_{PR})) (k(P_{RX} + P_{TX} + P_{PR})) \]

In the path discovery broadcasting mechanism, each node broadcasts RREQ message it receives for the first time. All nodes in the range of the source node mean that they must broadcast when they receive requests directly from the source itself. This node additionally broadcasts this request again to its scope node, and this process continues until a target is found.

Based on the above discussion, let's assume a source node \( S \) performing a route discovery broadcasting to find its destination node \( D \) in a plane, where 20 intermediate nodes are randomly placed as shown in Fig.2. Let's assume power consumption unit for node transmission \( P_{TX} = 3 \), receiving \( P_{RX} = 1 \) and processing \( P_{PR} = 2 \). For a normal broadcasting and PSM based power consumption is computed using the equation-2.

![Fig.2: A PSM based Broadcasting](image)

Here, a number of \( k=23 \) in the case of normal broadcasting and \( k=13 \) in the case of PSM broadcasting. So, support on \( k \) value the normal broadcasting mechanism consume 230 power units and the PSM based broadcasting consumes 120 power units, which will be approx. 52% of power consumption in compare to normal broadcasting and saving approx. 48% power resources.

**B. Predetermined Energy Route for Data Routing**

Based on the path discovery mechanism above, we have the generally energy proficient nodes in the network. However, the power loss probability still occurs due to frequent
link loss or overload through the node support on the number of data packets transmitted. Therefore, it is very important to determine in advance the expected energy cost of transferring data on a particular path.

According to [4], the current distance to the destination node based exclusively on choosing the next hop neighbor. That is, it sends a packet to the neighbor adjoining to the destination. However, such a preference may perhaps not be the majority energy proficient link in the region, and the entire path may not be energy-efficient globally. In addition, the total distance travelled to reduce energy consumption have to be as minute as potential. Therefore, we establish a classified area that limits the direction of delivery. Based on these constraints, we have determined the energy-efficient path and determined the energy cost in advance. Therefore, we will focus on designing energy efficient local routing methods with high efficiency for random networks.

Let's assume we have route discovery path through PSM and found three major paths and the shortest path to reach the target, as shown in Figure 3. However, there is no guarantee that the shortest path obtained will be energy-efficient. A pre-determined energy strategy is to quickly uncover an energy-efficient path close to the mainly energy-efficient path and then route it to a preservation plan to increase energy efficiency.

![Fig.3: Prominent Route Discovered from S to D using PSM](image)

In Fig.3, shows the intermediate nodes between S and D as {1, 2, 3, 4, 5, 6}, and there are 3 shortest route is possible between S and D as, \{(S→1→2→D), (S→3→4→D), (S→5→6→D)\}.

In addition, we assume that the energy essential to continue transmission of the data all the way through a link a→b is represent as c(∥ab∥). We describe a perception of distance energy as an energy model c(d), where d is max distance a node can transmit. It is defined as a ratio between the transmission distance and the energy consumption of such transmission, i.e., d/c(d) .

Let's consider, \(d=j\), then the value for the energy consumption will be \(j/c(j) \leq \max(d/c(d))\). We identify, \(j/c(j)\) as the maximum distance energy beneath energy
consumption model $c(d)$. We believe that the distance energy $d/c(d)$ is a growing provision when $d<j$ and is a falling function when $d>j$.

Beneath this definite energy consumption model, the maximum distance energy may be $j = \sqrt{c}$. It is perceived that when $j \geq d$, the most excellent distance end-to-end of a forwarding link is $d$. Our proposed PEBER routing will acquisitively select the links which can maximize the energy efficiency.

Denote the set of paths between the source and the destination by $W$, the number of hops for path $w$ by $N_w$, and the energy consumption for link $l$ in path $w$ by $E_{w,l}$, then the set of shortest paths $W_s$ would be,

$$W_s = \min(N_w), w \in W$$

And, the sum of minimum energy for the shortest paths will be denoted as $W_{SP}$, and computed as,

$$W_{SP} = \min\left(\sum_{w=1}^{N} E_{w,l}\right), w \in W_s$$

The $W_{SP}$ may have additional than one minimum energy shortest path, but a routing protocol is able to select an exclusive path support on certain criteria, such as an arrival time request packet. The first condition causes the node to pick the shortest path and the second situation selects the minimum energy path on the entire shortest paths to support on the link cost table.

**Table-1: Link Cost Table**

<table>
<thead>
<tr>
<th>Next Hop</th>
<th>Distance $(d)$ in meter</th>
<th>Primary Hop Energy $(E_a)$</th>
<th>Minimum Energy Req. $(d/E_a)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S→1</td>
<td>1</td>
<td>$E_s = 9$</td>
<td>0.11</td>
</tr>
<tr>
<td>S→3</td>
<td>2</td>
<td>$E_s = 9$</td>
<td>0.22</td>
</tr>
<tr>
<td>S→5</td>
<td>2</td>
<td>$E_s = 9$</td>
<td>0.22</td>
</tr>
<tr>
<td>1→2</td>
<td>1</td>
<td>$E_1 = 5$</td>
<td>0.2</td>
</tr>
<tr>
<td>3→4</td>
<td>3</td>
<td>$E_3 = 7$</td>
<td>0.42</td>
</tr>
<tr>
<td>5→6</td>
<td>2</td>
<td>$E_5 = 6$</td>
<td>0.33</td>
</tr>
<tr>
<td>2→D</td>
<td>1</td>
<td>$E_2 = 8$</td>
<td>0.12</td>
</tr>
<tr>
<td>4→D</td>
<td>3</td>
<td>$E_4 = 9$</td>
<td>0.33</td>
</tr>
<tr>
<td>6→D</td>
<td>1</td>
<td>$E_6 = 6$</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Based on the Table-1 we can calculate the probable predetermine energy required using the equation-4 for each path from $S$ to $D$. 
Table-2: Predetermine Energy Table

<table>
<thead>
<tr>
<th>Path</th>
<th>Probable Predetermine Energy Req. ($P_E$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S→1→2→D</td>
<td>$P(0.11+0.2+0.12) = 0.43$</td>
</tr>
<tr>
<td>S→3→4→D</td>
<td>$P(0.22+0.42+0.33) = 0.97$</td>
</tr>
<tr>
<td>S→5→6→D</td>
<td>$P(0.22+0.33+0.16) = 0.71$</td>
</tr>
</tbody>
</table>

Based on the pre-determined energy values in the Table-2, we choose the majority energy efficient path for data routing. The performance results of PEBER are evaluated in the next section.

IV. PERFORMANCE EVALUATION

This segment provides details on the performance evaluation of the proposed approach. The proposed algorithm has been tested with network parameters such as speed and packet size. PEBER's performance is evaluated in provisions of "throughput", "predetermined energy efficiency", and "routing overhead". The proposed PEBER was compared with traditional DSR [21] and PEER [10] to evaluate improvisation.

- **Throughput**: The throughput is defined as, "Ratio of the number of packets originated at the source to the Number of packets essentially received at the destination". It is utilized to analyze that the network capacity has not been reduced using energy extensions to the MAC protocol.

- **Energy efficiency ($P_E$)**: It is defined as, "Total number of packets transmitted/Total energy consumed". The entire packets transmitted is determined by summing up the total "Route request"($REQ_{TX}$), "Route reply"($REP_{TX}$), "Route error"($RERR_{TX}$), "Control Packets"($CTR_{TX}$) and "Data Packets"($DP_{TX}$) and total energy consumption is the summation of everyone node’s energy consumption throughout the simulation time. The higher the $P_E$ the better the energy efficiency will be considered.

\[ P_E = \frac{\sum(REQ_{TX} + REP_{TX} + RERR_{TX} + CTR_{TX} + DP_{TX})}{TotalEnergyConsumption} \]

- **Routing Overhead**: It is defined as, "Total number of control packets produce for the period of the simulation time".

A. **Simulation Setup**

The simulation is performed in two scenarios. First, we perform mobility with varying numbers of nodes to assess energy efficiency during scalability, and second, we change
mobility rates to assess the impact of frequent distance changes between nodes. The configured parameters are shown in Table-3.

**Table-3: Simulation Parameters**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Parameter Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Area</td>
<td>1000m X 1000m</td>
</tr>
<tr>
<td>Packet Size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>CBR Rates</td>
<td>4 pkts/sec</td>
</tr>
<tr>
<td>Mobility</td>
<td>RWP</td>
</tr>
<tr>
<td>Pause Time (sec)</td>
<td>60</td>
</tr>
</tbody>
</table>

**For Scenario-1:** *(Varying Number of Nodes)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Nodes</td>
<td>20, 40, 60, 80, 100</td>
</tr>
<tr>
<td>No. of (S-D)Pairs</td>
<td>5, 10, 20, 30, 40</td>
</tr>
<tr>
<td>Mobility (m/s)</td>
<td>10</td>
</tr>
</tbody>
</table>

**For Scenario-2:** *(Varying Mobility Speed)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Nodes</td>
<td>50</td>
</tr>
<tr>
<td>No. of (S-D)Pairs</td>
<td>15</td>
</tr>
<tr>
<td>Mobility (m/s)</td>
<td>5, 10, 15, 20, 25</td>
</tr>
</tbody>
</table>

**B. Result Evaluation**

In respect to scenario-1, the respective results observed support on the number of node variation are shown in fig.5-7 between DSR, PEER, and PEBER.

**Fig.5. Throughput Comparison**

**Fig.6. Throughput Comparison (Mobility)**
The comparison results show an improvisation over traditional DSR and PEER protocol in both the scenarios. In the case of throughput all three have to maintain constant fall rate but PEBER shows a 25 - 30% better throughput in compare as shown in Fig.5 and 6, and at the same time, it shows a 20 - 40 % reduction of routing overhead shown in Fig.7 and 8 also observed due to energy efficient route prediction. Fig. 9 and 10, shows the evaluation similarity of energy utilization efficiency. A high-quality difference in energy efficiency is observed due to efficient PMS based route discovery and data route prediction using PEBER mechanism.

V. CONCLUSION

In this paper, we propose an energy efficient routing for MANET. This approach provides energy efficient routing between source and destination even under dynamic mobility conditions. This approach utilizes the new power saving mechanism by reducing the reroute of the path discovery process in the MANET and establishes a preset energy efficient path for data routing to reduce energy requirements. The path identified in a predetermined energy efficiency process can be energy efficient enough for efficient data delivery. Experimental results show that energy efficiency comparisons are better in both node scalability and mobility scenarios. It also has lower
overhead and improved throughput compared to traditional methods. In future studies, assessing rapid changes in the network environment may result in an energy-efficient path that is not efficient over time and requires a recovery process to maintain efficiency.

REFERENCES


