# P-TECS: An Energy Balance Algorithm for Opportunistic Networks Integrating Multiple Node Attributes

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**Abstract.** This paper proposes an energy balance opportunistic networks routing algorithm P-TECS. The P-TECS solves the problems of energy consumption of key nodes in existing opportunistic routing algorithms. This paper defines the relay degree of communication between nodes, and designs a P-TECS opportunistic routing algorithm integrating dynamic attributes of multiple nodes. Simulation results show that in resource-constrained opportunistic networks, P-TECS significantly improves the message delivery rate and average remaining energy of nodes, and significantly reduces the routing overhead rate.

**Keywords:** Opportunistic routing algorithms · resource availability rate · node social engagement · communication relay degree

## 1 Introduction

Opportunistic network [1] is a new type of Mobile Ad-hoc network [2], which establishes communication by meeting opportunities between nodes. It does not need to form a complete communication link between the source node and the destination node, and the data are forwarded between the nodes in the "storage-carry-forward" manner. Opportunistic networks have irreplaceable advantages in the application of non-fully connected networks due to the characteristics of time-varying topology, node mobility and intermittent connectivity. In recent years, it has been widely used in the Internet of Vehicles, unmanned aerial vehicle, hydrometeorological monitoring, mine safety monitoring, wildlife tracking, mobile edge computing and other fields [3–8].

In opportunistic networks, the node's energy and buffer are consumed when forwarding messages, and attributes of these nodes are different. Existing opportunistic routing algorithms do not integrate energy balance and buffer optimization mechanisms of the node with various node-dynamic-attributes, which leads to the following two main problems in Opportunistic Networks:


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First, active nodes exit the network due to high energy consumption. The number of available key nodes for network communication is reduced, which leads to a low messages delivery rate.

Second, the nodes with insufficient buffers and infrequent social interactions discard more data in message forwarding, resulting in high routing overhead.

Therefore, this paper comprehensively considers the five dynamic attributes of nodes when selecting relay nodes to forward messages. It effectively solves the above problems and improves the message delivery rate of the whole network.

## 2 Related Works

Opportunistic routing algorithm based on node information selects relay nodes according to node attributes, which include encounter probability, encounter duration, remaining energy, remaining cache, social relations and so on.

Literature [9] proposed Prophet based on node historical throughput which integrates node historical throughput to calculate node encounter probability, improves message delivery rate, and reduces routing overhead rate and average delay. Prophet based on node cache awareness is proposed in literature [10]. This routing algorithm combines node cumulative contact time and node remaining cache to calculate node encounter probability, which improves message delivery rate and average remaining energy of nodes. Literature [11] proposes an opportunistic routing algorithm based on node energy awareness and node candidate set, which minimizes the number of nodes in the candidate set list of each source node, prolongs the network lifetime and improves the average remaining energy of nodes. Literature [12] proposes Prophet based on node energy awareness and node cache awareness. This routing algorithm combines node remaining energy and node remaining cache to calculate node encounter probability, which improves message delivery rate, prolongs network lifetime, improves average node remaining energy and reduces routing overhead rate. Literature [13] proposed an opportunistic routing algorithm based on node social relations which first extracts node decision attributes according to node social relations, then assigns weights to node decision attributes in combination with information entropy method and feature selection method, and then measures node social relations according to weight allocation results. Finally, relay nodes are selected according to measured node social relations, which improves message delivery rate and reduces routing overhead rate. The opportunistic routing algorithm based on dynamic social relations of nodes is proposed in Literature [14]. This routing algorithm designs a new model to establish dynamic social relations of nodes, and a new method to predict the movement mode and contact time of nodes, which improves the message delivery rate and reduces the average delay, message hop count and network load.

Although the opportunistic routing algorithms mentioned in the above literature improve the network performance to a certain extent, they do not comprehensively analyze the influence of node encounter probability, node cumulative encounter duration, node energy consumption, node cache usage and node social relationship on message forwarding. Therefore, the proposed opportunistic network energy equalization algorithm integrates the above five node attributes to solve the problem of energy consumption caused by excessive computation of key nodes and the problem of important message loss caused by node cache overflow.

## 3 P-TECS: An Energy Balance Algorithm for Opportunistic Networks Integrating Multiple Node Attributes

The communication relay degree between nodes is composed of five different node-dynamic-attributes (encounter probability, cumulative encounter duration, remaining energy, remaining buffer and social relationship between nodes) according to certain mathematical rules.

### 3.1 Obtain the Historical Encounter Information Between Nodes

**Definition 1.** *The encounter probability between nodes. In Opportunistic Networks, the possibility of two nodes encounter in the subsequent time is called the encounter probability between nodes, marked as* $P_{(a,b)}$.

When node $a$ and node $b$ encounter, their number of encounters increase, and in the subsequent time, manifested as their encounter probability increase, as shown in Eq. (1) [15]:

$$P_{(a,b)} = P_{(a,b)old} + (1 - P_{(a,b)old}) \times P_{ini} \tag{1}$$

Among, $P_{(a,b)old}$ is last encounter probability of two nodes, $P_{ini} = 0.75$ [15] is the initial probability.

**Definition 2.** *The cumulative encounter duration between nodes. In Opportunistic Networks, the sum of each encounter duration between two nodes is called the cumulative encounter duration between nodes, marked as* $T_{(a,b)}$.

When node $a$ and node $b$ encounter for the $n$-$th$ time, their cumulative encounter duration is the sum of the previous $n$-1 encounter durations, as shown in Eq. (2):

$$T_{(a,b)} = \sum_{i=1}^{n-1} t_{(a,b)i} \tag{2}$$

Among, $t_{(a,b)i}$ is the $i$-$th$ time encounter duration of two nodes.

### 3.2 Obtain the Resource Availability Rate of the Node

**Definition 3.** *The remaining energy ratio of the node. In Opportunistic Networks, the ratio of the remaining energy of the node to the initial energy of the node is called the remaining energy ratio of the node, marked as* $R_E$*.*

After node $a$ forwards message $m$ to node $b$, its remaining energy is updated, as shown in equation (3) [16]:

$$E_{rem,a} = E_{rem(old),a} - \frac{B_m}{B_{pkt}} \times E_{for} \tag{3}$$

Among, $E_{rem(old),a}$ is the energy before node $a$ forwards message $m$, $B_m$ is bytes of message $m$, $B_{pkt}$ is bytes of a data packet, $E_{for}$ is the energy consumed by node $a$ to forwards a data packet to node $b$.

After node $b$ receives message $m$ forwards by node $a$ and returns acknowledge characters, its remaining energy is updated, as shown in Eq. (4) [16]:

$$E_{rem,b} = E_{rem(old),b} - \frac{B_m}{B_{pkt}} \times E_{rec} \tag{4}$$

Among, $E_{rem(old),b}$ is the energy before node $b$ receives message $m$, $E_{rec}$ is the energy consumed by node $b$ to receive a data packet forwards by node $a$.

The remaining energy ratio of the node is the ratio of the remaining energy to the initial energy, as shown in Eq. (5) and Eq. (6):

$$R_E = \frac{E_{rem}}{E_{ini}} \tag{5}$$

Among, $E_{rem}$ is remaining energy after node forwards/receives the message, $E_{ini}$ is the initial energy of the node. The remaining energy ratio of the node reflect the energy consumption degree.

**Definition 4.** *The remaining buffer ratio of the node. In Opportunistic Networks, the ratio of the remaining buffer of the node to the initial buffer of the node is called the remaining buffer ratio of the node, marked as* $R_C$*.*

The remaining buffer ratio of the node as shown in Eq. (5):

$$R_C = 1 - \frac{\sum_{m=1}^{M} N_m \times B_m}{B_{ini}} \tag{6}$$

Among, $N_m$ is the quantity of message $m$ held by nodes, $B_m$ is bytes of message $m$, $B_{ini}$ is the initial buffer of the node. The remaining buffer ratio of the node reflect the buffer usage degree.

### 3.3 Obtain the Social Engagement of Nodes

**Definition 5.** *The social engagement of nodes: When nodes are detected by source nodes as neighbors, the number of network interfaces that they can work is called node social engagement, which reflects the situation that nodes provide network bandwidth. Node mobility may lead to different social engagement of nodes every time, so it is necessary to count the sum of social engagement of nodes every time, that is, the cumulative social engagement of nodes, which reflects the situation that nodes have social relations.*

When a node is detected as a neighbor node for the *n-th* time by the source node, the accumulated social engagement is the sum of the previous $n$-1 social engagement, as shown in Eq. (7):

$$S = \sum_{i=1}^{n-1} s_i \tag{7}$$

Among, $s_i$ is the *i-th* social engagement of the node.

### 3.4 Calculate the Communication Relay Degree Between Nodes

**Definition 6.** *The communication relay degree between nodes. In P-TECS, multiple nodes-dynamic-attributes are integrated, and the communication relay degree between nodes is constructed, marked as* $P - TECS_{(a,b)}$. *The greater the communication relay degree between nodes reflects the rationality of the relay node, that is, the larger the communication relay degree, the more reasonable the messages forwarding between nodes.*

The communication relay degree between nodes as shown in Eq. (8):

$$P - TECS_{(a,b)} = kP_{(a,b)} \times l(1 + \frac{T_{(a,b)}}{100}) \times oR_{E,b} \times pR_{C,b} \times q\frac{S_{a,b}}{10^5} \tag{8}$$

Among, $P_{(a,b)}$ is the encounter probability of node $a$ and node $b$, $T_{(a,b)}$ is the cumulative encounter duration of $a$ and node $b$, $R_{E,b}$ is the energy ratio of node $b$, $R_{C,b}$ is the buffer ratio of node $b$, and $S_{a,b}$ is the cumulative social engagement of node $a$ and node $b$. $k$, $l$, $o$, $p$ and $q$ are weights, the experiment shows that when $k = 0.6$, $l = 0.1$, $o = 0.1$, $p = 0.1$, $q = 0.1$, the effect is the best.

### 3.5 The Pseudo-code of P-TECS

As shown in Algorithm 1, energy-exhausted source nodes will enter the dormant state and no longer forward messages, and remaining source nodes forward messages to destination nodes or relay nodes. The relay node belongs to neighbor nodes of the source node and has the highest communication relay degree with the destination node. After the relay node receives message forwarded by the source node, it becomes the new source node.

**Algorithm 1** P-TECS: An Energy Balance Algorithm for Opportunistic Networks Integrating Multiple Node Attributes

**Input:** $sn$: the source node;

$cx$: the maximum of the message copies number;

$M$: the messages collection of the source node;

$RN$: the relay nodes collection of the source node;

$P - TECS_{(dn,rn)}$: the communication relay degree collection of the destination node and relay nodes collection of the destination node and relay nodes.

**Output:** $rn_{next}$: the next hop relay node of the message.

```
if sn.buffer.M == null then
    exit
end if
if sn.buffer.M != null then
    loop:
    for all m ∈ M do
        for all rn ∈ RN do
            if m.dn == rn then
                rn_next = rn
                forward m to rn_next
                delete m ∈ M
            end if
        end for
        for all rn ∈ RN do
            add p − tecs_(dn,rn) to P − TECS_(dn,rn)
        end for
        rn_next = rn_max        ▷ The p − tecs_(dn,rn) of rn_max and dn is the maximum in P − TECS_(dn,rn)
        forward m to rn_next
        m.copies = m.copies + 1
        if m.copies == cx then
            delete m ∈ M
        end if
    end for
    if sn.buffer.M != null then
        goto loop
    end if
end if
```

The algorithm flow of P-TECS is as follows:

Step 1: Judge whether $M$ in $sn$ cache is empty. If so, the algorithm ends, otherwise the algorithm continues. This step corresponds to lines 1 through 3 in the P-TECS pseudocode.
Step 2: For $m$ that can be delivered directly to $dn$, $sn$ directly delivers $m$ to $dn$, and $rn_{next}$ is $dn$ at this time, and deletes $m$ from $M$ after delivery. This step corresponds to lines 4 through 13 in the P-TECS pseudocode.
Step 3: For $m$ that cannot be directly delivered to $dn$, $sn$ delivers $m$ to $rn_{max}$. At this time, $rn_{next}$ is $rn_{max}$. After delivery, add copies of m from $M$. If the number of copies of $m$ is greater than $cx$, delete $m$ from $M$. This step corresponds to lines 14 to 23 in P-TECS pseudo code.
Step 4: Repeat steps 2 and 3 until $M$ in the $sn$ cache is empty. This step corresponds to lines 24 through 27 in the pseudo code.

## 4 Simulations and Analyses

### 4.1 Simulation Settings

This paper uses ONE [17] v1.6.0 as the simulation platform. The data obtained by this platform can be used to calculate the encounter probability, cumulative encounter duration, remaining energy, remaining buffer and social engagement of nodes. Comparing and analyzing the messages delivery rate, routing overhead rate, and average remaining energy of the node of P-TECS with Epidemic, Prophet, and EC-CW [18], the performance improvement of P-TECS to Opportunistic Networks can be evaluated. Both P-TECS and EC-CW contain the energy balance mechanism of the node, that is, nodes consider the impact of the remaining energy of the node on messages forwarding when selecting relay nodes. Simulation settings are shown in Table 1:

### 4.2 Results Analyses

It can be seen from Fig. 1 that as the initial cache of the node increases, P-TECS overall has the highest messages delivery rate. Epidemic uses the flooding mechanism to forward messages, which makes many nodes unable to receive messages due to energy consumption or cache overflow, and has a low message delivery rate. Prophet only forwards messages to the relay node with the highest probability of meeting the destination node, which reduces the possibility of node energy consumption or node cache overflow, and has a higher message delivery rate than Epidemic. EC-CW only forwards messages to the relay node with the highest communication relay degree with the destination node. The selected relay node has sufficient remaining energy and remaining cache, further reducing the possibility of node energy consumption or node cache overflow, and has a higher message delivery rate than Prophet. P-TECS selects relay nodes according to the communication relay degree of nodes that integrate the cumulative social engagement, which reflects the social relationship of nodes, making the

**Table 1.** Parameter settings of simulation.

| Category | Parameter | Value |
|---|---|---|
| Scenario settings | Simulation area size (m) | 4500 × 3600 |
| | Simulation time (s) | 10000–90000 |
| | Initial energy (mAh) | 240000 |
| | Scan energy (mAh) | 12 |
| | Transmit energy (mAh) | 10 |
| | Scan interval (s) | 100 |
| | Pedestrian nodes amount (pcs) | 40 × 2 |
| | Pedestrian nodes buffersize (MB) | 5–25 |
| | Tram nodes amount (pcs) | 2 × 3 |
| | Tram nodes buffersize (MB) | 50 |

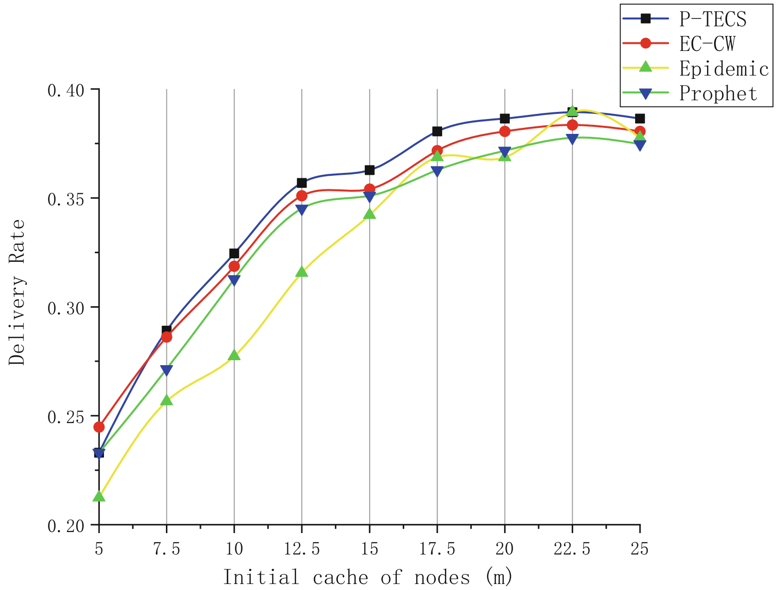


**Fig. 1.** The relationship between the messages delivery rate and the initial cache of the node.

relay nodes selected by P-TECS more likely to forward messages, reducing the possibility of messages being discarded because they are not forwarded within their lifetime, and having the highest message delivery rate overall.

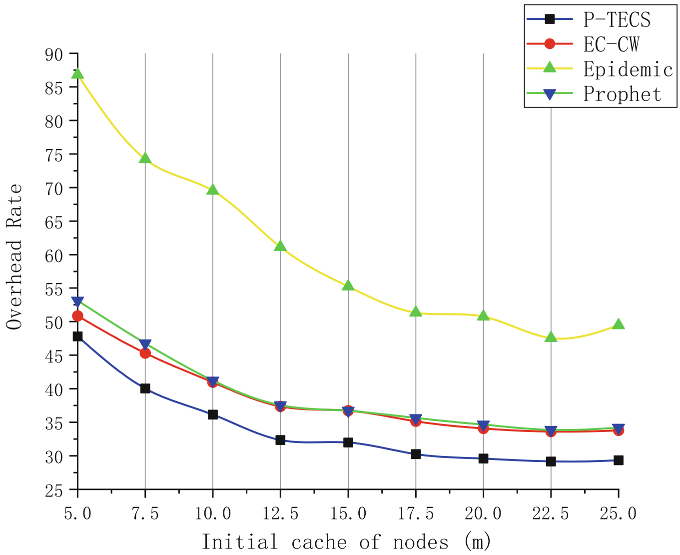


**Fig. 2.** The relationship between the routing overhead rate and the initial cache of the node.

It can be seen from Fig. 2 that as the initial cache of the node increases, P-TECS always has the lowest routing overhead rate. In Epidemic, nodes use the flooding mechanism to forward messages to all nodes that encounter, so Epidemic always has the highest routing overhead rate. Prophet only forwards the message to the relay node with the highest probability of meeting the destination node, and EC-CW only forwards the message to the relay node with the highest communication relay degree with the destination node. Both of them consume less network resources, and their routing overhead rates are similar. P-TECS selects relay nodes according to the communication relay degree of nodes integrating cumulative social engagement, which reduces the possibility of messages being discarded because they are not forwarded within the lifetime, reduces the number of message replicas, consumes the least network resources, and always has the lowest routing overhead rate.

It can be seen from Fig. 3 that as the initial cache of the node increases, P-TECS always has the highest average remaining energy. Epidemic uses the flooding mechanism to forward messages, which consumes the most energy and always has the lowest average remaining energy of nodes. In this simulation, Prophet uses the node sleep mechanism to make nodes with less remaining energy enter the sleep state and no longer forward messages. EC-CW uses the node energy balance mechanism to reduce the possibility of nodes with less remaining energy becoming relay nodes. Both of them balance the node energy consumption, and the average remaining energy of the two nodes are similar. In addition to using the node energy balance mechanism, P-TECS also reduces the number of mes-

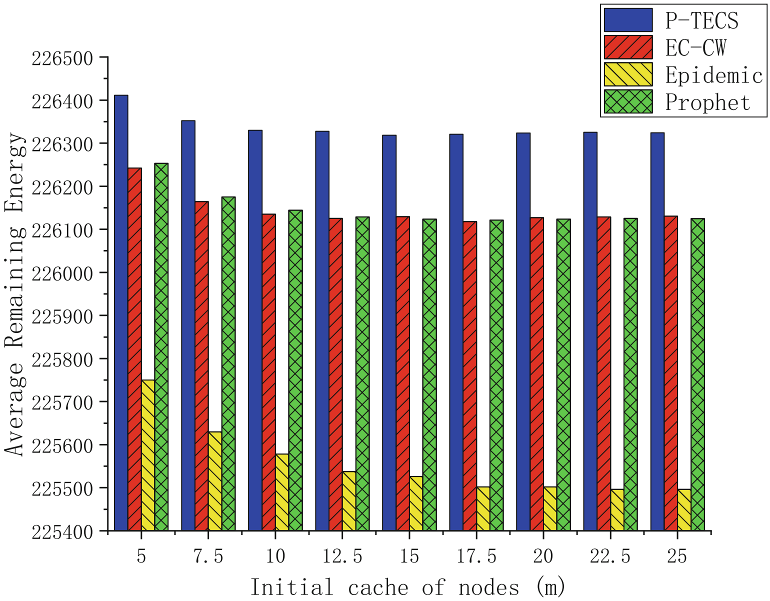


**Fig. 3.** The relationship between the average remaining energy of nodes and the initial cache of the node.

sage replicas, further reduces the node energy consumption, and has the highest average remaining energy of the node.

## 5 Conclusion

Existing opportunistic routing algorithms rarely integrate energy balance and buffer optimization mechanisms of the node with various node-dynamic-attributes, which leads to the following two main problems in opportunistic networks: active nodes enter the dead state prematurely due to they consume too much energy; nodes with insufficient buffer and infrequent social interaction discard many messages during the messages forwarding process. To solve the above challenges, this paper defines the communication relay degree between nodes based on the encounter probability, cumulative encounter duration, remaining energy, remaining buffer and social relationship between nodes, and then P-TECS: an energy balance algorithm for opportunistic networks integrating multiple node attributes is proposed. The simulation results show that in resource-constrained Opportunistic Networks, P-TECS significantly improves the messages delivery rate and the average remaining energy of nodes, and significantly reduces the routing overhead rate.

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