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► To cite this version:

Jingwen Luo, Jia Wu, Yuzhou Wu. An Efficient Data Transmission Strategy for Edge-Computing-Based Opportunistic Social Networks. 17th IFIP International Conference on Network and Parallel Computing (NPC), Sep 2020, Zhengzhou, China. pp.323-335, 10.1007/978-3-030-79478-1_28. hal-03768754

HAL Id: hal-03768754

<https://inria.hal.science/hal-03768754>

Submitted on 4 Sep 2022

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An Efficient Data Transmission Strategy for Edge-Computing-Based Opportunistic Social Networks

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Abstract. As wireless network has developed rapidly in recent years, especially with the maturity and wide application of 5G wireless system, millions of mobile users have been able to quickly exchange large amounts of data in social networks. Despite the positive impact of the recent advances in edge computing on opportunistic social networks (OSNs), classical OSN algorithms rely on only a few source nodes to forward data, which often results in data transmission delay, excessive resource consumption and even loss of source nodes. Therefore, we propose an efficient edge-computing-based data transmission strategy in OSNs. It classifies nodes into new communities according to their degree of association. Source nodes forward data through relay nodes in community, which effectively reduces the resource consumption of a single node. The experiment results of comparison with the three algorithms show that the proposed method can effectively reduce the resource consumption during data transmission as well as enhance the information transmission efficiency.

Keywords: Edge Computing · Opportunistic Social Networks · OSNs · Data Transmission · Data Management.

1 Introduction

The development of wireless network coupled with mobile devices has contributed to the rapid development of social networks in recent years, therefore users are able to enjoy different kinds of services and applications [1]. Especially with the rapid application of 5G (5th Generation Wireless Systems), the number of mobile terminals and devices increases significantly, reconstructing the social networks. Millions of mobile users have been able to quickly exchange large amounts of data in the social network, forming a significant network paradigm in 5G [2]. Mobile devices that are carried by users are characterized by a strong randomness and mobility, making them a social node, and the correlation between nodes can help establish communities [3].

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Also, innovations keep emerging in different fields, with mobile edge computing included, which will dramatically affect social networks [4]. By incorporating edge computing into the opportunistic social networks (OSNs), the system can better evaluate users' current situation in the social network, optimize the network by calculating and evaluating, and give reasonable selection suggestions. It can significantly increase the data transmission of nodes and effectively reduce the network's data transmission delay.

In OSNs, Vahdat et al. proposed the Epidemic routing algorithm [5], and Lu et al. proposed an improved Epidemic scheme which is energy-saving n-epidemic algorithm [6]. However, those algorithms adopt flooding techniques to transmit data, which increases the network overhead significantly. Spyropoulos et al. brought forward the Spray and Wait routing algorithm [7], and Wang et al. brought forward a dynamic Spray-and-Wait algorithm [8]. The calculation and update of node quality by those algorithm can be restricted by the energy consumption. Edge computing as a new computing paradigm in recent years, which, in social networks, could be capable of solving many issues like latency, limited battery life of mobile devices, and bandwidth cost, etc [9, 10].

However, edge computing can not completely solve the existed problems in OSNs where nodes search opportunities to exchange data in the way of "store-carry-forward" in their communities [11]. For the traditional opportunistic algorithms, a lot of communities use one or two nodes existing in the social network for information delivery. Those nodes have to transmit a large amount of data as well as calculate many tasks that will consume more energy [12, 13]. In the traditional opportunistic network protocol, due to the lack of enough cache or overhead for source node, data transmission may cost a long time in the community [11]. What's worse is that for these nodes, information transmission will consume many resources by using flooding technology and data will be lost as the source node dies.

To solve above-mentioned limitations, the paper focuses on proposing an efficient data transmission scheme based on edge computing in OSNs, reconstructing the community taking into account to which degree the edge or the source node is associated with the neighbor nodes. The correlated community nodes take charge of a data transmission task, i.e., allocating some source nodes. The proposed scheme is capable of reducing source node consumption as well as prolonging the source node's life cycle. The paper mainly makes three contributions as follows.

- Regarding community reconstruction, source nodes are required to conduct reconstruction based on the degree of association between nodes, and information transmission shall be performed in proper communities;
- The proposed algorithm is characterized by an effective information delivery and is capable of reducing the energy consumption by source nodes during data transmission;
- As shown by experiments, the method can dramatically lower the energy consumption as well as enhance the delivery efficiency of data.

2 System Model

In OSNs, the scarcity of source nodes and ineffective information transmission may cause the enormous resources consumption of single source node and the death of source node, finally data carried by the source node will loss. For preventing the nodes resource from being over-consumed as well as reducing the node death rate, it is necessary to focus on searching some proper adjacent nodes for helping the source node to deliver a part of data. On that account, we define the changing theorems of communities and propose a data transmission algorithm with a high effectiveness based on edge computing in this section.

2.1 Community Definition

Suppose a user sends a data download request to the associated network. Firstly, considering the download content and the user's information, the system can check whether the associated edge or source nodes have the cache data. If yes, the system can decide who (edge user or source node) sends the requested information directly to the mobile user based on channel, correlation, and energy consumption, etc. If not, edge user or source nodes will get current data based on their computing power, channel conditions, degree of association, energy consumption, and so on, and then send the obtained data to the requested user. The process is shown in Fig. 1.

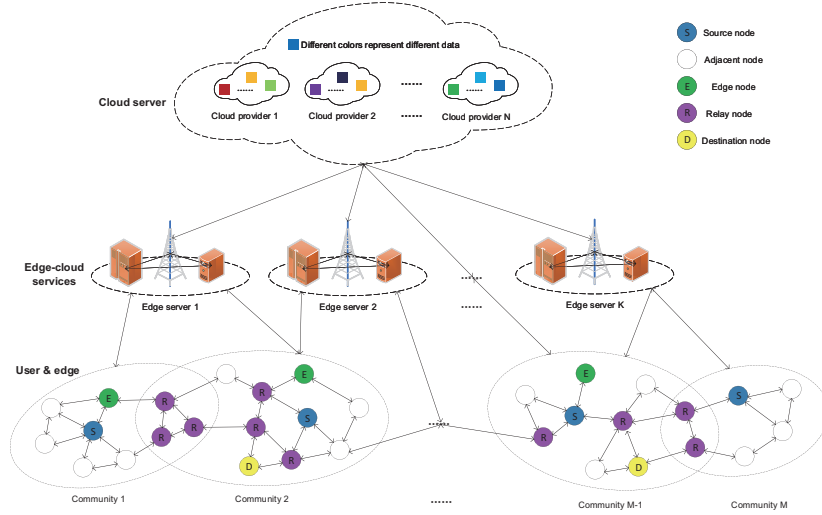


Fig. 1: The opportunistic social networks with edge computing.

However, in the process of user movement, the community of node may change. Therefore, the changing form of communities during user movement shall be proved.

Based on the weighted networks in social networks [14], the network topological structure can be expressed as $G=(N, E, \omega)$, where N represents the node number in current network, E can be expressed as $N = \{(a, b) \mid a \in N, b \in N\}$, both of a and b is nodes, ω is the weight between a and b . There are n adjacent nodes for source node N_s at t moment, and $n \subseteq N$. When source node and adjacent node meet the condition $v\omega_{ij} \geq \theta$, the source node can forward information through the adjacent node, which can be called relay node. $v\omega_{ij}$ represents the association between source node N_i and adjacent node N_j , v stands for a coefficient, ω_{ij} means weight between N_i and N_j , and θ stands for the threshold. Here the structural degree exhibited by community is defined as S_X , which can predict the changes in the community X .

$$S_X(t) = \frac{\omega_x}{T} - \frac{\omega_s^2}{(2T)^2} = \frac{4T\omega_x - \alpha_s^2}{(2T)^2} \quad (1)$$

$S_X(t)$ denotes the structural degree exhibited by community X , T means the total weight in networks, ω_x means the total weight of community X , α_i means the total degree of N_i , $\Delta\omega$ denotes the weight variation, ω_{ij} denotes the edge weight between N_i and N_j , E_X^i denotes the total edge weight of N_i in X . The theorem and proof are as follows.

Theorem 1. *When the community X is divided into two sub-communities X_i and X_j , it should satisfy the requirements $\frac{\alpha_i\alpha_j}{2T} < \omega_{ij} < \Delta\omega + \frac{\alpha_i\alpha_j + \alpha_s\Delta\omega + \Delta\omega^2}{2(T+\Delta\omega)}$.*

Proof. Suppose the community X is split into sub-communities of X_i and X_j , and considering the increase in the total weight of community,

$$\begin{cases} \omega_i + \omega_j < T \\ \frac{S_i}{T} - \frac{\alpha_i^2}{4T^2} + \frac{S_j}{T} - \frac{\alpha_j^2}{4T^2} < \frac{\alpha_i + \alpha_j + \omega_{ij}}{T} - \frac{(\alpha_i + \alpha_j)^2}{4T^2} \\ \omega_{ij} > \frac{\alpha_i\alpha_j}{2T} \end{cases} \quad (2)$$

With the decrease in the given total weight, it is possible to rewrite the formula as follows.

$$\omega_i^* + \omega_j^* > T^* \quad (3)$$

$$\omega_{ij} < \Delta\omega + \frac{\alpha_i\alpha_j + \alpha_s\Delta\omega + \Delta\omega^2}{2(T + \Delta\omega)} \quad (4)$$

Thus, the sub-communities X_i and X_j satisfies the theorem $\frac{\alpha_i\alpha_j}{2T} < \omega_{ij} < \Delta\omega + \frac{\alpha_i\alpha_j + \alpha_s\Delta\omega + \Delta\omega^2}{2(T+\Delta\omega)}$, then the community X is separated.

Theorem 2. *During node N_i movement, the edge of the node N_i connects node N_j and becomes the only edge of node N_j . With the decline of the weight between N_i and N_j , N_j can not be separated from the community.*

Proof. Similar to theorem 1, the assumption that edge weight reduction between N_i and N_j is represented by Δw , $\Delta w < 0$. With the separation of community

X, below theorem should be satisfied.

$$\begin{cases} \omega_i + \omega_j < T \\ \frac{4T\omega_i - \alpha_i^2}{(2T)^2} + \frac{4T\omega_j - \alpha_j^2}{(2T)^2} < \frac{4T(\alpha_i + \alpha_j + \omega_{ij}) - (\alpha_i + \alpha_j)^2}{(2T)^2} \\ \omega_{ij} > \frac{\alpha_i \alpha_j}{2T} \end{cases} \quad (5)$$

ω_i^* and ω_j^* is the edge weight of N_i and N_j after community X separate, T^* is the community total weight ater separate. Then,

$$\begin{cases} \omega_i^* + \omega_j^* > T^* \\ \omega_{ij} < \frac{\varepsilon_s \varepsilon_i + \varepsilon_s \Delta\omega + \Delta\omega^2}{2(\kappa + \Delta\omega)} + \Delta\omega \end{cases} \quad (6)$$

That is

$$\frac{\alpha_i \alpha_j}{2T} < \omega_{ij} < \frac{\alpha_i \alpha_j + \alpha_i \Delta\omega + \Delta\omega^2}{2(T + \Delta\omega)} + \Delta\omega \quad (7)$$

It can be explained as

$$\frac{\alpha_i \alpha_j}{2T} < \omega_{ij} < \frac{\alpha_i \alpha_j + \alpha_i \Delta\omega}{2(T + \Delta\omega)} \quad (8)$$

Because

$$\frac{\alpha_i \alpha_j + \alpha_i \Delta\omega}{2(T + \Delta\omega)} - \frac{\alpha_i \alpha_j}{2T} = \frac{\alpha_i \Delta\omega (T - \alpha_j)}{2T(T + \Delta\omega)} < 0 \quad (9)$$

$\frac{\alpha_i \alpha_j}{2T} < \omega_{ij} < \frac{\alpha_i \alpha_j + \alpha_i \Delta\omega + \Delta\omega^2}{2(T + \Delta\omega)}$ is a false proposition.

Hence, the only edge of N_j connects N_i and the weight decreases. N_j can not be separated from the community.

Theorem 3. N_i in community X, the edge weight as well as the weight of community Y increase, satisfying the equation $4(T + \Delta\omega)(E_Y^i - E_X^i + \Delta\omega) + (\alpha_i + \Delta\omega)(\alpha_X - \alpha_Y - \alpha_i) - \Delta\omega^2 > 0$, thus it is possible for N_i to join into community Y.

Proof. Community X and Y see rising edge weight, and communities' structure degree is:

$$S_X + S_Y = \frac{2T\omega_X - (\alpha_X + \Delta\omega)^2}{4(T + \Delta\omega)^2} + \frac{2T\omega_Y - (\alpha_Y + \Delta\omega)^2}{4(T + \Delta\omega)^2} \quad (10)$$

With N_i leaving community X as well as jointing into community Y, communities' structure degree is:

$$S_{X-i} + S_{Y+i} = \frac{4T(\omega_X - E_X^i) - (\alpha_X + \Delta\omega)^2}{4(T + \Delta\omega)^2} + \frac{4T\omega_Y - (\alpha_Y + \Delta\omega)^2}{4(T + \Delta\omega)^2} \quad (11)$$

To proof that the the join of N_i will increase the structure degree exhibited by community Y, it is necessary to first proof $S_{X-i} + S_{Y+i} > S_X + S_Y$.

$$4(T + \Delta\omega)(E_Y^i - E_X^i + \Delta\omega) + (\alpha_i + \Delta\omega)(\alpha_X - \alpha_Y - \alpha_i) - \Delta\omega^2 > 0 \quad (12)$$

Above theorems assist in proving the changes of community in the course of node movement.

2.2 Data transmission model

During the data transmission of OSNs, multiple hop transmission is needed to deliver data to destination nodes. Besides, the delivery of complete data to community node is usually conducted in an overlay way, which will greatly increase the routing overhead as well as the energy consumption. Therefore, an Edge-Computing-based Efficient Data Transmission (ECEDT) scheme is designed to reduce the routing overhead as well as the energy consumption of source nodes. In this scheme, the source node N_s and the relay nodes communicate with each

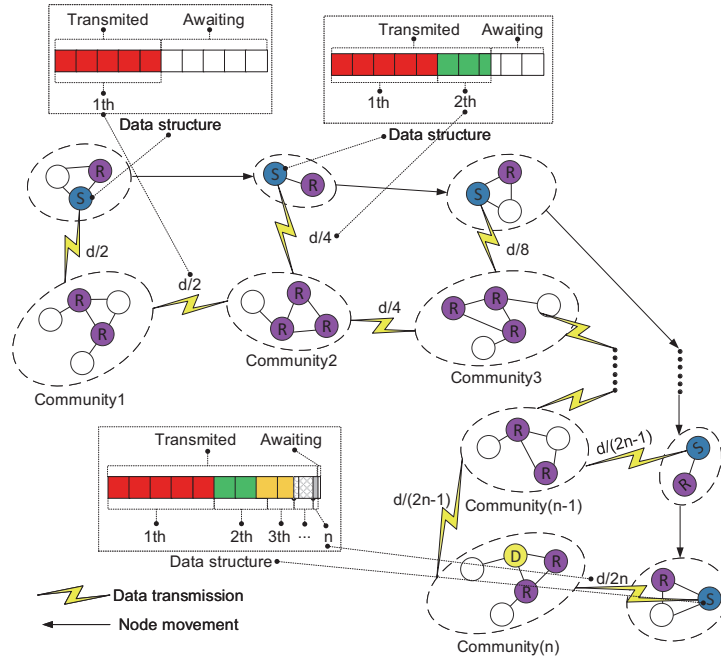


Fig. 2: The process of data transmission.

other, with the later receiving as well as storing certain data from the former. Relay nodes take charge of broad information transmission to other nodes. The movement of source node is along with searching for relay nodes from adjacent nodes, as well as reconstructing the old community into new ones. Reconstructed communities are able to relieve the pressure suffered by source node for data transmission and information spread, which enables the transmission of data on the line. For a clear description of the delivery process of information, how ECEDT scheme works is explained below:

Step 1: The total data that are carried by the source node N_s are expressed as $\mathcal{T}_0(\vartheta) = \vartheta_0$, and N_s sends a message of "HELLO" to the adjacent nodes for searching those that can be used in a community.

Step 2: After receiving the message of “HELLO” in the community, the adjacent node will give a response, followed by establishing a connection to the source node. If adjacent node meets the condition $v\omega_{ij} \geq \theta$, it can be converted into a relay node.

Step 3: The source node begins to communicate with the relay node, together with transmitting 50% of data to the relay nodes of community with multiple perceptions. With the source node marking the completion of data transmission, the relay node regarding community 1 will receive information from N_s after the first data transmission (as shown in Fig. 2).

Then, the information carried by community 1 are as follows.

$$\mathcal{T}_1(\vartheta) = \frac{1}{2}\mathcal{T}_0(\vartheta) = \frac{1}{2}\vartheta_0 \quad (13)$$

$\mathcal{T}_{sur1}(\vartheta)$ represents the surplus data that were unset by N_s after the first transmission.

$$\mathcal{T}_{sur1}(\vartheta) = \mathcal{T}_0(\vartheta) - \mathcal{T}_1(\vartheta) = \vartheta_0 - \frac{1}{2}\vartheta_0 = \frac{1}{2}\vartheta_0 \quad (14)$$

Step 4: The source node keeps moving, together with sending the message of “HELLO” as well as searching for relay nodes.

Step 5: The source node firstly communicates with community 2, followed by sending 50% of data that are unset to the nodes in the community. Also, data are transmitted between communities, and the nodes in community 1 are capable of broadcasting 50% of the information provided by the source node (Fig. 2).

Information below are received by community 2:

$$\mathcal{T}_2(\vartheta) = \frac{1}{2}\mathcal{T}_{sur1}(\vartheta) + \mathcal{T}_1(\vartheta) = \frac{1}{2^2}\mathcal{T}_0(\vartheta) + \mathcal{T}_1(\vartheta) = \frac{3}{4}\vartheta_0 \quad (15)$$

Below equation describes the surplus information that are unset by N_s after the second transmission:

$$\mathcal{T}_{sur2}(\vartheta) = \mathcal{T}_0(\vartheta) - \mathcal{T}_2(\vartheta) - \mathcal{T}_1(\vartheta) \quad (16)$$

As is well known, data of community 2 covers all the data provided by community 1, i.e. $\mathcal{T}_1(\vartheta) \subseteq \mathcal{T}_2(\vartheta)$. Therefore, equation (16) can be rewritten into:

$$\mathcal{T}_{sur2}(\vartheta) = \mathcal{T}_0(\vartheta) - \mathcal{T}_2(\vartheta) = \vartheta_0 - \frac{1}{2^2}\vartheta_0 - \frac{1}{2^1}\vartheta_0 = \frac{1}{4}\vartheta_0 \quad (17)$$

The source node marks the unset surplus information and keeps moving.

Step 6: It is assumed that communities can achieve data communication, therefore, with the source node meeting the community 3 and beginning to transmit information, community 3 is able to see the message from the previous two communities.

$$\mathcal{T}_3(\vartheta) = \frac{1}{2}\mathcal{T}_{sur2}(\vartheta) + \mathcal{T}_2(\vartheta) + \mathcal{T}_1(\vartheta) = \frac{7}{8}\vartheta_0 \quad (18)$$

The surplus information are marked by source node, and the source node keeps moving. Equation 17 shows the surplus information unsent by N_s after the third transmission.

$$\mathcal{T}_{sur3}(\vartheta) = \mathcal{T}_0(\vartheta) - \mathcal{T}_3(\vartheta) = \vartheta_0 - \frac{1}{2^3}\vartheta_0 - \frac{1}{2^2}\vartheta_0 - \frac{1}{2^1}\vartheta_0 = \frac{1}{8}\vartheta_0 \quad (19)$$

Step 7: Repeat abovementioned procedures.

Step 8: With the source node searching for target nodes community after information transmission is performed for n times, $\frac{1}{2^n}\mathcal{T}_0$ denotes target node's community information, and $\sum_{k=1}^{n-1}\mathcal{T}_k(\vartheta)$ denotes the communication data between different communities. Figure. 2 displays the entire transmission process.

When $n \rightarrow \infty$, the ECEDT scheme transmits the same amount of information with the Epidemic and Spray and Wait algorithm. If the data are transmitted for a long time, those received by the destination node will be more complete. And ECEDT, Epidemic and Spray and Wait exhibit a time complexity of $O(2n-1)$, $O(n)$ and $O(2n)$ respectively. But the routing overhead of ECEDT, Epidemic and Spray and Wait is $\sum_{k=1}^n (\frac{1}{2})^k = 1 - (\frac{1}{2})^n$, n and n . ECEDT has an obviously lower routing overhead compared with Epidemic and Spray and Wait $n \rightarrow \infty$.

3 Simulation and Analysis

For evaluating the performance exhibited by ECEDT, a simulation tool named Opportunistic Network Environment (ONE) is adopted [15], and is compared with the three basic approaches, i.e. Information cache management and data transmission (ICMT) algorithm [16], Status estimation and cache management (SECM) algorithm [17], and Spray and Wait algorithm [7].

The experiment sets the simulation parameters: The simulation time lasts for 1-6 hours, and the network area is 4500m×3400m. The transmission adopts the broadcast pattern, that involves 400 nodes moving at 0.5 to 1.5m/s in a random manner. Each node has 5MB cache storage information. The social model is adopted for nodes for data transmission, and each node has the max transmission domain of $10m^2$. Data packet is sent each 25-35s at the transmission speed of 250KB/s. The initial energy of each node reaches 100 Joules, and 1J energy will be consumed for sending a data packet. Based on the simulation report data, the experimental results are shown in Fig. 3-4.

Figure 3 shows the relationship between time and four parameters. In Fig. 3(a), the transmission rates of Spray and Wait(copy=30 and copy=10) and SECM are lower than ECEDT. Spray-and-Wait and SECM algorithms deliver information to nodes by copying a large amount of duplicate information and using the flooding method, leading to more information loss. ICMT algorithm controls the time interval of delivery information that improves the transmission and receiving of effective information, which is its delivery ratio higher than the other two. ECEDT combining multi-sensing community and mobile node transmission base on edge-computing, the transmission rate of the algorithm is effectively improved and is the highest among all algorithms.

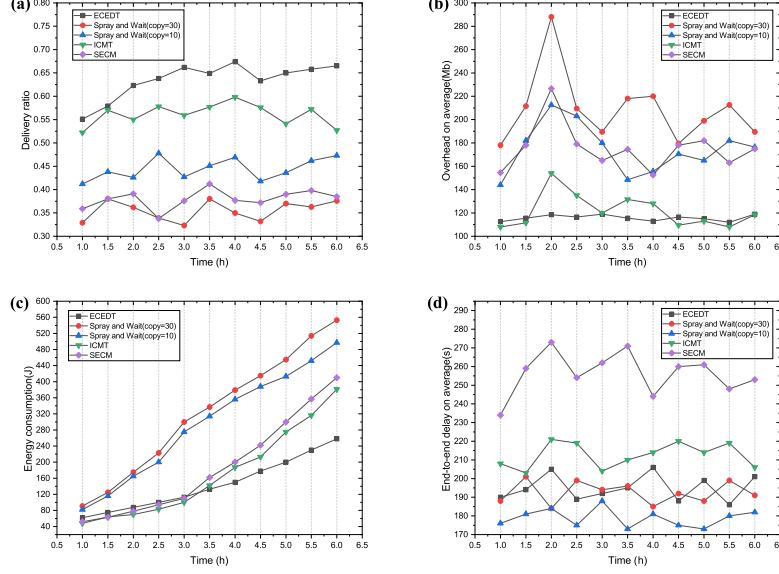


Fig. 3: Relationship between time and different parameters.

In Fig. 3(b), the routing overhead of the ECEDT is maintained steady, and ICMT's performance is also good. But the routing overhead of Spray and Wait routing algorithm(copy=30) is highest. Spray and Wait(copy=10) and SECM have a local flooding phenomenon, which overhead remains in a high range.

In Fig. 3(c), the energy consumption of Spray and Wait is highest, and each node needs energy to transmit information through spray. Several communities bear the energy consumption and extend the information transmission time of nodes in the ECEDT algorithm, thus reducing the number of information transmission times to source nodes. The energy consumption of the ECEDT is less than the other.

In Fig. 3(d), the SECM adopts a encounter delivery method that mass copied information transmit, and its average delay is highest. ECEDT's delay remained in a fairly good range. The transmission delay of Spray and Wait is lowest. It can indicate that their information diffusion capability is strong.

Node ache acts as a significant indicator for social networks and can directly impact algorithms' transmission efficiency. Fig. 4 displays the relationship between cache and 4 parameters. In Fig. 4(a), Spray and Wait algorithm adopts flooding method, and its delivery ratio is lowest. The raising delivery ratio of ECEDT is significant in increasing node cache due to combining community and node mobile delivery data. ICMT's delivery rate is also good.

Figure. 4(b) show that a larger node cache can reduce the node overhead. The routing overhead of the ECEDT drops faster than the other three.

In Fig. 4(c), ECEDT adopts a data delivery method assisted by the community that reduces energy consumption significantly. Other algorithms' energy

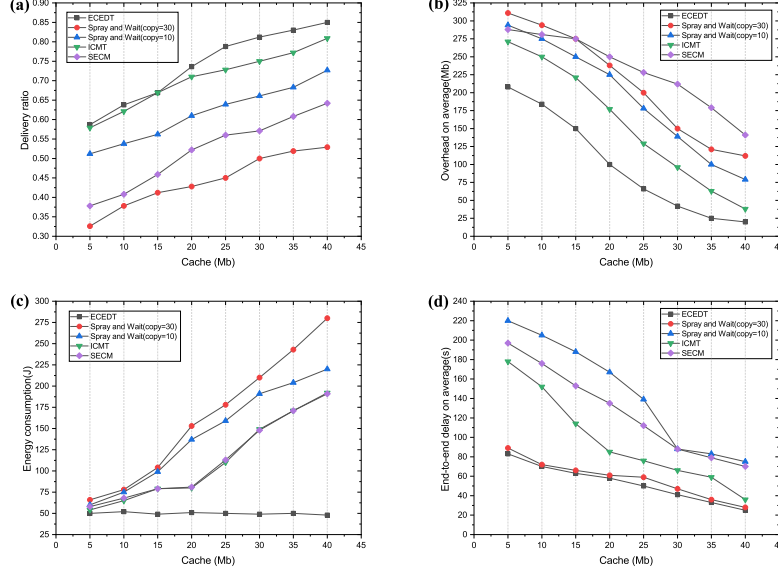


Fig. 4: Relationship between cache and different parameters.

consumption increase as the cache enlarges, while ECEDT's energy consumption remains steady.

Figure. 4(d) show that the delivery delay decline with the increasing cache, the delay of ECEDT and Spray and Wait(copy=30) lower than the other two algorithms.

Based on the above experiment analysis, ECEDT performs better than other algorithms with regard to the transmission rate, the energy consumption and the routing overhead, however, it exhibits a higher time delay than that of the Spray and Wait routing algorithm. In practice, ECEDT performs better regarding the information transmission for a long time.

The actual environment sees different kinds of information transfer approaches. Hence, it is necessary to attach importance to various moving approaches. Three different mobile modes are chosen for confirming the performance exhibited by ECEDT, namely Shortest Path Map Based Movement (SPMBM), random way point (RWP), and random walk (RW) [15]. The simulation results are shown in Figure. 5.

In Fig. 5(a), the RWP model exhibits the best overall performance and the largest delivery rate, and the RWP model exhibits a higher delivery rate than the RW model.

In Fig. 5(b), considering the node movement process as well as the information transfer process, community can share information with abundant nodes while transferring information and reconstructing node. The routing overhead of ECEDT suffers a slight impact, and the routing overhead of the three models ranges from 110 to 120.

In Fig. 5(c), the three models present a slightly different energy consumption. As shown in the result, ECEDT exhibits a stable performance for node information transmission, and model change consume many energy.

In Fig. 5(d), for three models in the range of 185-220, RW and SPBM present the largest and smallest delay, respectively. The results demonstrate the effectiveness of SPBM model of ECEDT regarding information transmission.

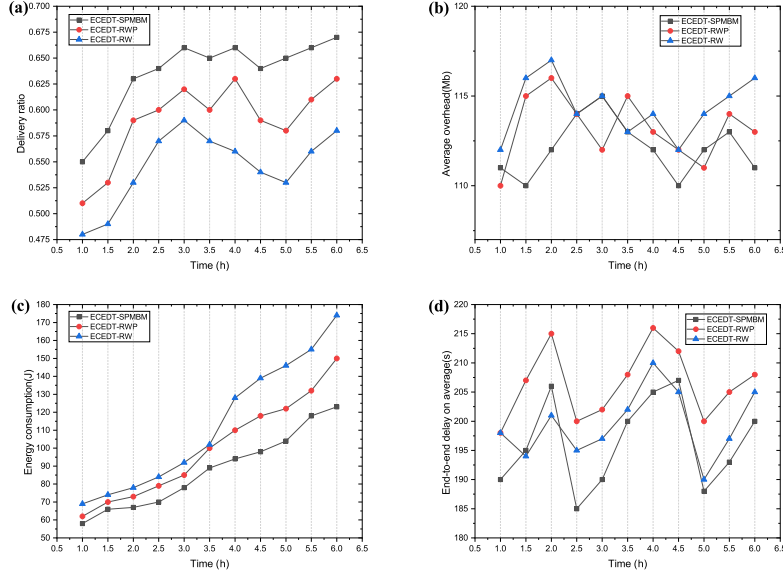


Fig. 5: Relationship between time and different parameters in three mobile models.

4 Conclusion

The paper focuses on designing a data transmission scheme with a high efficiency, i.e. (edge-computing-based efficient data transmission (ECEDT)), which can assist in solving the problem that source nodes consume excessive energy. The performance exhibited by traditional opportunistic network algorithms is compared and analyzed. As indicated by the experiment, the proposed scheme can well transmit data and performs excellently in three mobile models, which demonstrates its steadiness in various environments. In edge-computing-based OSNs, the proposed scheme is capable of lowering nodes energy consumption, prolonging the life cycle of network as well as remarkably enhancing the efficiency of data transmission. The future work is suggested to pay attention to energy consumption reduction regarding source nodes and relay nodes.

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