Network Structure Aware Dynamical Routing Mechanism in Social Intermittently Connected Wireless Networks

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ABSTRACT
The nodes in intermittently connected wireless network have social attributes, and their movement has special rules. According to the analysis on the transition regularity of each node in its movement epochs, the nodes in the network are classified into two categories, central nodes and common nodes respectively. With the constrained label propagating method, the network topology is decomposed into several communities. Further, the network structure aware routing mechanism is proposed in our paper. To improve the network performance of packet delivery ratio with minimized overhead induced, the central nodes and common nodes of the destination community are selected as the relay nodes, and the activity of central node can be taken full advantage by the source node. Results and numerical analysis show that the proposed routing mechanism improves the network performance dramatically; especially almost 90% improvement can be achieved in terms of delivery ratio.

Keywords
intermittent connected wireless network; social network; community detecting; centrality node; community routing

1. INTRODUCTION
Unlike the store-forward packet transmission manner in MANETs, the communication opportunities raised by node movement are utilized reasonably in intermittently connected wireless network. The packets generated by source node are stored and carried by relay nodes, and then forwarded to other nodes opportunistically [2, 12]. Based on the packet forwarding principle for the intermittently connected networks, the transmission procedure should be cooperated by several relay nodes. [14，17].

The mobile terminals carried by human beings constitute the typical social intermittently connected networks. By actual measurement for the personal wireless network, the particular phenomenon has been found, named as "Big World, Small World" [5]. Usually, the network topology can be logically divided into several communities according to the congregation degree of the nodes in the network. The nodes can be divided into two classes, central node and common node. Obviously, the central node is quite active, and its probability of migrating into other communities is much higher [1].

In this paper, we propose a novel network structure aware dynamical routing mechanism which takes the social feature of nodes into account. The main contributions of the paper are as follows:

(1) A node centrality estimation scheme for social intermittently connected network is introduced. With our defined parameter of node centrality, the central node can be selected by comparing the value of node centrality mutually.

(2) A neighbor discovery scheme is designed according to the historical information of movement. To meet the dynamical feature of network, this scheme can adjust the relation between nodes when the node joins or leaves the network.

(3) To detect the network structure, a constrained label propagation method is proposed in our paper. With the constraints of node relationship, the overhead can be reduced.

(4) Based on the results of node relation evaluation method, the network structure aware routing mechanism is proposed. The transmission opportunities brought by the common nodes and central nodes are utilized efficiently. As a result, the delivery ratio of packets can be enhanced dramatically; at the same time, the cost can be effectively controlled.

The remainder of the paper is organized as follows. In Section II, some related works are surveyed, and the node centrality estimation method, neighbor discovery policy and community structure detecting mechanism are introduced in Section III. In Section IV, based on the results of network structure detecting, the structure aware routing mechanism is carefully designed. In Section V, we evaluate the accuracy of our proposed network structure detecting mechanism, and compare the proposed routing mechanism with previous works. Finally, the conclusion and the future works are given in Section VI.

2. RELATED WORDS
The routing mechanism in intermittently connected network aims to ensure the reliability[6].Obviously, the time varying network topology is the biggest challenge for packets forwarding [16], and

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the network state information can be utilized to assist this procedure. Ref. [9] proposes a disseminating method, especially for the network with low node density. Further, the mean delay and control overhead of network state information forwarding scheme are analyzed. The results show that network topology information should be disseminated partially to minimize control overhead. where the parameter of Residual Hop Counter (RHC) is used to limit the hop count of packet. Together with the forwarding probability, the packet sending is determined.The parameter of encounter rate is defined in Ref. [13], and future connectivity is predicted according to the information related to previous encounters.

Recently, social networking is occupying a large portion of an individual's daily life, combining the social characteristics of people and wireless communication devices, community-based routing mechanism for intermittently connected network has gained more attention.Utilizing the clustering characteristics of all the nodes in community, the community based packet transmission scheme (CMTS) is proposed in Ref. [8]. Based on the contact frequencies among the nodes in the network, the network is divided into several communities; moreover, the number of copies and relays are determined by CMTS. Based on the social network analysis, Ref. [7] proposes a routing mechanism for intermittently connected networks. From the observation on several realistic data sets, the conclusion is drawn that one-hop neighbors can cover most range of the whole network. With the two-hop delegation query scheme, the value of social utility for each neighbor is determined.The social context between nodes is considered in the HiBOp [4], the nodes that show an increasing match with the known context attributes of the destination are selected as relay nodes. One of the main drawbacks of HiBOp is about its high overhead. The mathematical model for optimal routing is formulated in Ref. [15]. To avoid redundant copying of packets, the routing mechanism is designed based on social relations between the nodes. Results show that the proposed mechanism provides better delivery ratio comparing with other protocols.

3. NETWORK STRUCTURE DETECTION

3.1 Node Centrality

Two parameters including encounter time and interval are used to depict the encounter of nodes. The former is defined as the time it takes for them to first exchange packets. The latter is the duration of the time interval between two consecutive contacts.According to the movement of nodes, their status can be classified into two classes, local status and roaming status respectively. While the number of encountered nodes sharing the same home community with a given node is larger than the number of nodes from other communities, the node status of epoch is viewed as local; otherwise, the node status of epoch is viewed as roaming.

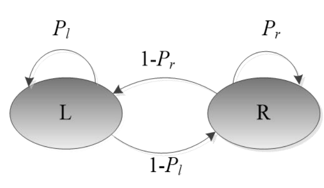


Figure 1 Node Status Transiting Model

Based on the foundation of social intermittently connected networks, the node status transiting model can be established as shown in Fig. 1, where pl denotes the probability that the node keeps its local state in the next epoch; pr denotes the probability that the node keeps its roaming state at the next epoch； L,R denotes two nodes . For certain epoch, let $\pi_l^{(i)}$ denotes the probability of local status and $\pi_r^{(i)}$ denotes the probability of roaming status, different status of node under steady state can be expressed by Eq. (1) and Eq. (2). For the given period, the node status can be illustrated by the probability of steady state.

$$\pi_l^{(i)} = \frac{1 - p_r^{(i)}}{2 - p_l^{(i)} - p_r^{(i)}} \tag{1}$$

$$\pi_l^{(i)} = \frac{1 - p_l^{(i)}}{2 - p_l^{(i)} - p_r^{(i)}} \tag{2}$$

Let i and j denote the central node and common node respectively, the average number of epochs for the two nodes under the roaming status during the given period is shown in Eq. (3), where $\pi_r^{(i)}$ and $\pi_r^{(j)}$ denote the probability of node with roaming status.

$$\frac{\hat{e}_i}{\hat{e}_j} = \frac{\pi_r^{(i)}}{\pi_r^{(j)}} \tag{3}$$

For given period, the proportion of roaming epochs of node can be used to evaluate its centrality. The higher proportion of roaming epochs, the more frequency that node roams among communities, thus the nodes with higher activity degree are more appropriate to act as the central node.

$$Centrality\quad(i) = \frac{\hat{e}(i)_r}{\hat{e}(i)_r + \hat{e}(i)_l} \tag{4}$$

Where the Centrality(i) is the centrality value of node i, and it is used to describe the frequency of handoff among communities, $\hat{e}(i)_i$ and $\hat{e}(i)_r$ are the epoch number of node with local status and roaming status during the given period. As can be seen, the centrality can be determined according to their own social attributes, and the values are different for individual nodes.

3.2 Neighbor Discovery

According to the temporal and spatial attributes of end-to-end path, the parameter of meeting frequency is utilized to determine the relationship between nodes. By analyzing the historical information recorded by the node locally, the neighbor nodes can be discovered in a distributed manner. The historical information includes two items, node ID and meeting times respectively, and the structure can be shown in Figure 2.

Figure 2 Meeting Times Table

Node u_1	Node u_2	……	Node u_n	Average
(u_1,c_{u1})	(u_2,c_{u2})	……	(u_n,c_{un})	C_{ave}

The corresponding items are updated dynamically while the network status exchanges, and the meeting frequency can be calculated by Eq. (5) and Eq. (6).

$$C_{sum} = \sum_{i=1}^{n} c_{ui} + \sum_{j=1}^{m} c_{vj} \tag{5}$$

$$C_{ave} = C_{sum} / \left(m+n\right) \tag{6}$$

For the node k in the network, the relation between other nodes can be determined by comparing the parameter of meeting frequency as shown in Eq. (7), where c_{uk} denotes the meeting times between node k and node u. Node u is viewed as the neighbor of node k while their meeting times are larger than the average meeting times.

$$c_{uk} \geq C_{ave} \quad (7)$$

3.3 Community Structure Detecting

According to the label propagating method [10], we proposed the cost efficient community detecting mechanism, which is named SACD (Similarity aware Community Detecting).Then an efficient data forwarding mechanism is designed to improve the network performance. To limit the overhead, the label comparing and updating process should satisfy the following constraints: (1) the encountered node is the neighbor node, as shown in Eq. (7); (2) the centrality of two kinds of node should meet certain proportional relationship as shown in Eq. (8).

$$\begin{aligned} \frac{Centrality\ (j)}{Centrality\ (i)} &= \frac{\hat{e}_r^{(j)} / \left[\hat{e}_r^{(j)} + \hat{e}_l^{(j)}\right]}{e_r^{(i)} / \left[\hat{e}_r^{(i)} + \hat{e}_l^{(i)}\right]} \\ &= \frac{\hat{e}_r^{(j)}}{\hat{e}_r^{(i)}} \times \frac{\hat{e}_r^{(i)} + \hat{e}_l^{(i)}}{\hat{e}_r^{(j)} + \hat{e}_l^{(j)}} \\ &\geq \frac{\hat{e}_r^{(j)}}{\hat{e}_r^{(i)}} = \frac{\pi_r^{(j)}}{\pi_r^{(i)}} \end{aligned} \quad (8)$$

Overall, the proposed label propagating and central node selecting process are summarized as follows:

STEP 1. The label of nodes is initialized as their unique identification; at the same time, node centrality value is set to zero;

STEP 2. The value of $\text{Centrality}(i)$ is updated when the next movement epoch of node starts, and the corresponding values are compared while the nodes meet each other.

STEP 3. The corresponding values of entries in meeting times table are updated according to the historical information recorded locally.

STEP 4. After the table is updated, the average encounter times C_{ave} is re-computed according to the Eq. (6).

STEP 5. The label of nodes is updated when the two conditions are satisfied as shown above, and the node with larger centrality value is currently viewed as central node, so the corresponding value is updated.

4. NETWORK STRUCTURE AWARE ROUTING MECHANISM

Based on the results of node centrality estimation and network structure detection method, the CCR (Community Centrality Routing) mechanism is proposed in this paper. Usually, in order to improve the delivery ratio and reduce the overhead, the basic principle is to select the central node as the relays for the node within the same community.

In the process of data forwarding proposed in this paper, nodes first forward data to the primary central node. When the primary central node is in busy state and is unable to receive data sent from other nodes, a node forwards data to the auxiliary central node with the second priority, completing data forwarding under the help assist of auxiliary center node. The results show that the mechanism we proposed can make full use of the encounter between nodes and decline the data transmission delay.

The home community of the encountering node can be obtained after the nodes meet each other; moreover, the centrality can also be acquired. When the label of encountering node N_j is the same as the label of its home community, it is to say that N_j is the central node. If its home community is the destination community of packet carrying by the relay nodes, the packet should be duplicated and forwarded to this central node. The forwarding policy is shown in Eq. (9).

$$R_{ij} = \begin{cases} 1, & (uniqueID_j = Comm\_label_j) \\ 0, & (uniqueID_j \mathrel{!=} Comm\_label_j) \end{cases} \quad (9)$$

Where $UniqueID_j$ is the unique identification of node, the $Comm\_label_j$ is the label of home community.

In social intermittently connected networks, the moving parameters are selected randomly during each epoch, whether the nodes are on the local status or roaming status. As a result, the node may never meet with the destination node even if it reaches the home community of destination. Therefore, the parallel transmission strategy is introduced in our routing mechanism. To reduce the overhead, the copy number is set to two. For these two cases, the central node and common node of destination community can be selected as the relays. While the copies are carried by source node and relay node, the transmission process is implemented in a distributed way by these two nodes. As a whole, the packets are carried by the node with the same home community of destination; at the same time, the relay node carries the copy of packet to its home community; finally, the copy can be transmitted to the destination node successfully.

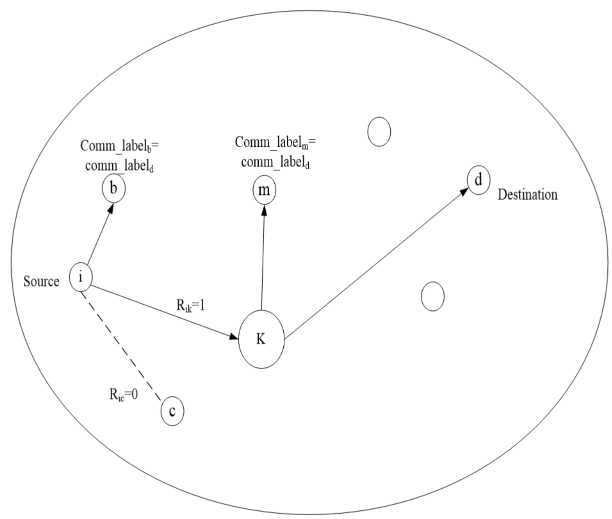


Figure 3 Transmitting path selecting

For the network topology shown in Figure 3, the packet transmitting by our proposed CCR is shown in detail as follows.

(1) When source node i generates a new packet, it first determines whether the destination node of this packet is in the same community as node i. If so, put into the send queue, and the packet is forwarded through Direct Routing (DT) . Otherwise, proceed to Step 3.

(2) Determine whether the message has been successfully received by the destination node, if so, the message will be deleted , or the message will be kept until these two nodes meet.

(3) Node i only forward data to two kinds of nodes: (1) central node of its local community; (2) other nodes belonging to the same community as the destination node.

(4) If a node encounters central node k from local community, it determines whether node k is busy. If node k is idle, the packets will be forwarded to node k. If node k encounters the

destination node in the process of its movement, node k will deliver packets directly. If it is in busy state, the direct delivery will be accomplished by auxiliary central nodes. Otherwise, proceed to Step 5.

(5) Determining whether an encounter node belongs to the same community as the destination node (as node b and node m shown in figure). If that is indeed the case, data forwarding process will continue. When node b or node m receives data, the data will be delivered using DT method in step 1, or else it continues to wait for opportunities of forwarding.

(6) Repeat the steps above, until the data delivery is successfully accomplished.

For the central node and common node in the network, the packet forwarding is quite different, and the pseudo-codes are shown as bellow.

Table I Pseudo-code for common node data forwarding

```
Common Node:

ExchangeDeliverableMessages();//Destination meet, delivery directly
  for(each connection of AllConnections)
     if(Router of otherNode_is_Transferring) ||
                    (other.Comm_Label==currentHost().Comm_Label)
        continue; //The meeting node is busy or the home community is the same, the
                 node freezes
     end if;
     For(each message of AllMessages) // traversal of every packet sending procedure

      if(Comm_Label of m.destinationNode != Comm_Label of currentHost() &&
         (otherNode. uniqueID == Comm_Label of currentHost() ||
         Comm_Label of m.destinationNode==otherNode.Comm_Label))
          //The label of meeting node is the same as the label of destination
           community or the meeting node is central node
     AddToSendCache(this message);//Add the packet into sending buffer
     if(Router of central Node_is_Transferring) &&
         Comm_Label of m.destinationNode != otherNode.Comm_Label))
       //The central node is busy or the label of meeting node is different from the labe
         of destination community
     Forward message to assist center node
     end if;
     end if;
   end for;
  end for;
```

Table II Pseudo-code for central node data forwarding

```
Central Node:

ExchangeDeliverableMessages ();     //Destination meet, delivery directly
  for(each connection of All Connections)
    for(each message of All Packets)    //Traversal of every packet
        AddToSendCache(this packet);     //Add the packet into sending
buffer
        DeletePacket(con.getPacket().getID());   //Delete the packet after
         the sending procedure
        end if;
    end for;
  end for;
```

5. NUMERICAL RESULTS

The ONE platform is utilized to evaluate our proposed routing mechanism, and the parameters are set as Table III. The link layer in this paper adopts Bluetooth 3.0 technology to communicate. And the main work of this paper is to detect the network structure, then to design efficient data forwarding mechanism.

Table III Parameter Setting

Parameter	Value
Network Area (m^2)	4500×3400
Simulating Time (h)	24
Node Number in Each Community	30
Transmitting Range (m)	10
Transmitting Speed (kBps)	250
Packet Interval (s)	[25, 35], exponential
Buffer Size (M)	5M
Packet Length (kb)	[80, 150], exponential
Speed (m/s)	1-6
Community Number	4
Primary Central Node Number	4
Pause Time (Seconds)	0-10

5.1 Accuracy of Network Structure Detecting

The centrality difference is defined as the probability difference between the probabilities of a central node and a common node roaming to other communities and the probabilities of a common node roaming to other communities. The bigger the difference is, the more active this central node is in the whole network. Therefore, verifying the proposed mechanism SACD is crucial in different centrality difference setting, and the results are shown in Fig. 4. The most used HCDA is used to compare with our mechanism. As can be seen, with the increment of difference on the node centrality, the accuracy of our proposed mechanism is getting better. For the cases of lower difference between different kinds of node, common nodes become more active, and the node cannot determine the social feature of the encountered node.

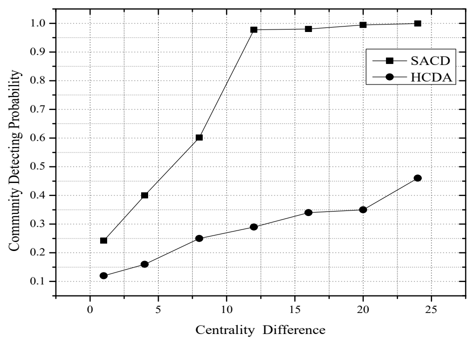


Figure 4 The accuracy of SACD under different centrality

For various intensity of node in each community, Figure 5 shows the accuracy of both mechanisms. From the results, the accuracy of SACD is relatively high, and the maximum value is up to 99.89%; moreover, with the increasing of density for the community, the accuracy of the SACD mechanism is also stable. It can be seen that the proposed mechanism has more scalability. Though the performance of HCDA algorithm can be optimized with the larger community scale, it is difficult to meet the needs of practical application.

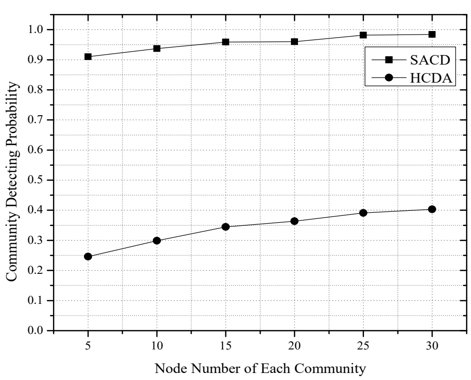


Figure 5 Accuracy of SACD under different node number of each community

5.2 Network Performance

The network performance of our proposed mechanism is evaluated in this sub-section. The classical routing mechanisms are used to validate the advantages of our mechanism.

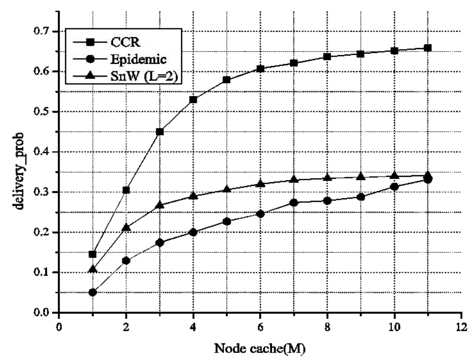
The performance parameters include delivery ratio and overhead ratio, where the overhead ratio is defined as the proportion between redundant packet forwarded times and the successful delivery number, as shown in Eq. (10). On the other hand, the delivery ratio can be defined as the fraction of generated packets to which at least one replica is eventually responded.

$$P_{overhead} = (N_t - N_s) / N_s \qquad (10)$$

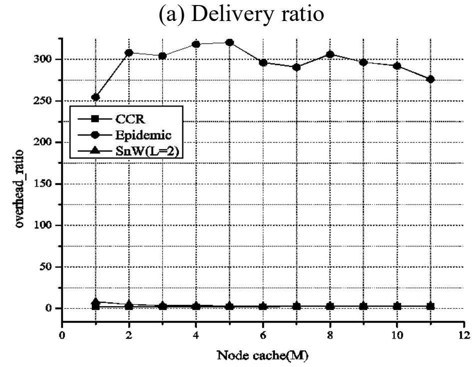
Where $P_{overhead}$ is the overhead ratio, N_r is the total times for packet forwarded, N_s is the number of successful transmitted packet $N_t - N_s$ is the redundant packet forwarded times.

For these three routing mechanisms, the proposed CCR and SnW are two hop routing mechanisms, and the Epidemic is the multi-hop routing mechanism. To make a fair comparison, the copy number of SnW is set to two, thus the copy numbers are the same as for the CCR and SnW. And the default value of message TTL is 300 min.

From the results shown in Fig. 8 (a), the delivery ratio ascends as the capacity of buffer for all the routing mechanism arises, but the case of CCR is 50% higher than the SnW; at the same time, it is 90% higher than the Epidemic. Among these routing mechanisms, the main difference is the selection on the relay nodes. As can be seen, the selection on the relay nodes is random. Therefore, the delivery ratio is very low for the Epidemic and SnW. On the contrary, network performance can be obtained by the CCR with the exploitation on the social feature of nodes. The overhead ratio for these routing mechanisms is shown in Fig. 8(b). It can be seen, the overhead ratio of epidemic is the highest, and the cases for the CCR and SnW are nearly the same degree. Obviously, the relay node set of Epidemic is the largest of all the three routing mechanisms, so more nodes are needed for the packet transmission. Consequently, the overhead induced into the network is the largest. On the other hand, the copy number of CCR and SnW is set to two, so their overhead ratio is the same degree. Further, the overhead ratio of CCR is lower than that of the SnW.



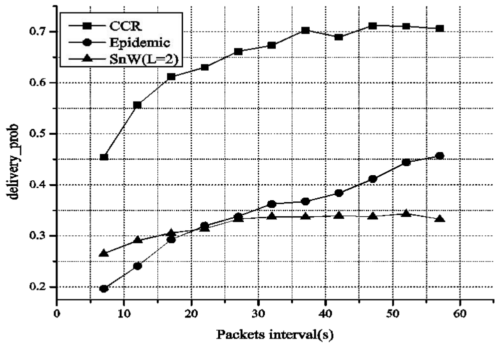
(a) Delivery ratio



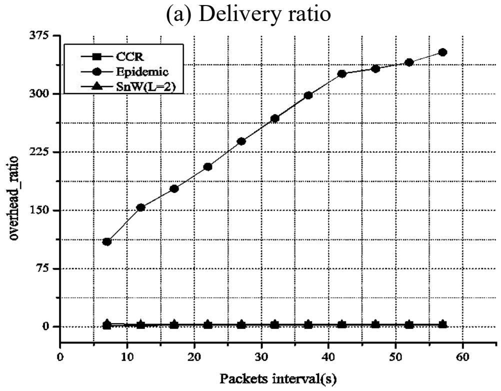
(b) Overhead Ratio

Figure 8 Network Performance under Different Node Cache

The network load can be denoted by the parameter of packet interval, and the performances of these three mechanisms under different network load are shown in Fig. 9. From the results shown in Fig. 9(a), the CCR is twice higher than the SnW and Epidemic. For the selection on the relay node, CCR routing is the most reasonable. Usually, it needs to wait for the center node. Therefore, longer delay may be induced into the network. Further, for the cases of higher network load, the CCR routing mechanism can take full advantage of the limited network resources. The performances of overhead ratio are shown in Fig. 9(b). For the Epidemic routing mechanism, the copy number increases with the heavier the network load; on the other hand, the copies injected into the network by CCR and SnW are constant. As a result, the performance of overhead ratio for CCR and SnW have loose coupling with the network load.



(a) Delivery ratio



(b) Overhead Ratio

Figure 9 Network Performance under Different Events Interval

6. CONCLUSION

For the social intermittently connected network, the nodes have typical social attributes. And the packet forwarding process is influenced by multiple factors in that the network sources are relatively limited. With the proposed routing method, node gradually detects the network structure and node important degree. Further, the central node is reasonably selected as the relay node during the packet forwarding process. With the exploitation of activity from central node, the packets are carried and forwarded to the community of destination node. Our proposed routing mechanism selects the relay nodes reasonably, and it can be dynamically adjusted according to the network status. As a result, the utilization of network resources can be effectively improved.

7. ACKNOWLEDGMENTS

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