Community-Based Adaptive Buffer Management Strategy in Opportunistic Network

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Abstract. Networks composed of devices, which having short-range wireless communications capabilities and carried by people, is a major application scenarios in opportunistic network, whose nodes movement has the characteristics of community. In this paper, we combine nodes meeting frequency with nodes separation duration time to assign nodes to communities, and present a community-based self-adaptive buffer management strategy in opportunistic network. The strategy makes decisions of buffered messages discarding and message transmission scheduling based on nodes' community attribute. At the same time, it generates message feedback adaptively according to the message delivery status, to remove unnecessary redundancy copies of messages in nodes buffer timely, then to reduce buffer overflow and avoid many unnecessary messages transmission. Simulation results show that the strategy can effectively improve the message delivery ratio and has significant lower network overhead.

Keywords: Opportunistic network · Community · Buffer management · Transmission scheduling

1 Introduction

Since the node mobility, the time of interruption is always longer than the time of connection in opportunistic networks, which makes it difficult to establish a live communication link between nodes [1, 2]. Messages forwarding between nodes take the pattern of storage-carrying- forwarding [3, 4]. For improving the success rate of messages transmission, it often needs to make many copies of a message. In the situation of limited space in node buffer and limited communication opportunity between nodes, messages always can't reach destination node timely and have to stay in nodes buffer for a long time, which always leads to overflow of nodes buffer. So it is a very meaningful to take effective buffer management strategy for improving routing protocol performance in opportunistic networks.

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2 Related Work

Many buffer management strategies only consider the state of the node itself to make buffer replacement decisions, such as DF (Drop Front) [5], which makes a FIFO(First In First Out) messages queue and always drops the forefront messages in buffer queue; DO (Drop the Oldest) [5], which discard the oldest messages, namely the messages having the least remaining lifetime, in nodes buffer; DRA (Drop-random) [6], which discard messages in the node buffer randomly. These strategies don't consider the case of network, and all have larger limitations.

Some buffer management strategies, which use the network information among nodes in opportunistic networks, have more excellent transmission performance. Literature [7] proposes a HBD(History Based Drop) strategy which drops messages based on nodes meeting history. It proposes a distributed algorithm based on message meeting dispatcher theory, and uses statistical learning method to approach global knowledge to optimize specific performance indicators. Literature [8] manages messages in node buffer using the ACK confirmation information issued in the network, and discards buffered messages timely according to the received ACK information to avoid buffer overflow.

Most existing buffer management strategies focus on priority problems of message discarding when buffer overflowed, and pay less attention on avoiding buffer overflow and transmission scheduling problem of buffered messages. And most of them don't consider the characteristics of node mobility when deciding buffer management strategy. There is a great relation between messages forwarding efficiency and node mobility model in opportunistic networks. The network composed of devices, which carried by people and having the ability of short-range wireless communications, is a very important application scenario in opportunistic networks [9–11]. Its nodes movement has the phenomenon of gathering, reflecting the characteristics of community. According to meeting history information of nodes and delivery status of messages in such network, we propose a CABMS (Community based Adaptive Buffer Management Strategy) strategy. Then we analyze and contrast CABMS strategy with three other buffer management strategies, which are Drop Front(DF), Drop the Oldest(DO) and Drop Based on History(HBD).

3 Community-Based Mobility Model in Opportunistic Networks

3.1 Community-Based Node Mobility Model

The opportunistic network composed of devices, which carried by people and having the ability of short-range wireless communications (Bluetooth /Wi-Fi, etc.), has the characteristics of the community. Its nodes movement always has the phenomenon of gathering due to relatively stable social relationships among people and certain dependence each other, and it always forms some more stable communities. We name such network as community opportunistic network. Within the community, the node density is relatively high, and the meeting frequency is higher. On the other hand, nodes in different community have lower meeting frequency, and some nodes are relatively active, often travel among several communities and enhance the contact among communities.

3.2 Community Detection Method

CABMS strategy improves the efficiency of buffer management in opportunistic network by detecting and using the characteristics of the human community. It assigns nodes to different communities according to closeness degree of node contacts. The detail method is listed as follows:

Shaded block in Fig. 1 represents that node i and node j are in the communication range of each other in the time interval of [0, T].

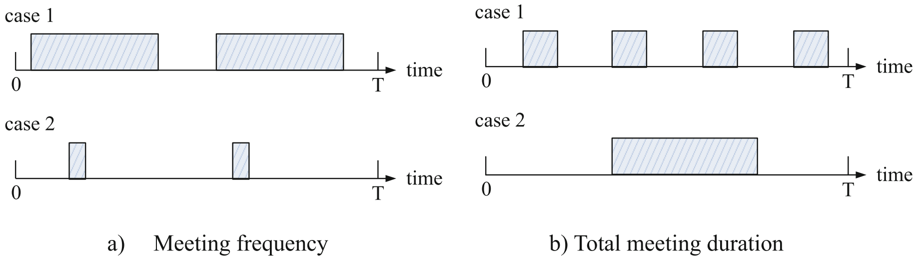

Fig. 1. The comparison of node encounter

In sub graph (a) of Fig. 1, both cases have only two blocks, that is, two nodes only meet twice in the time interval T. But the width of the box in the first case is much larger than that of the second case. Although the encounter frequency are the same in both cases, but the length of contact time between the nodes in the first case is much longer than that of the second case, so the communicate opportunity of first case is much better than that of the second case. In sub graph (b) of Fig. 1, even though the total contact time between nodes are the same in both cases, in the first case nodes can contact more other nodes to exchange relevant information for periodically separation, and nodes can exchange data better for cycle of connection, which makes data dissemination more effective.

Consider these encounter cases in Fig. 1, we propose a new measure rule to reflect the encounter frequency and encounter duration time.

$$AVG(S_{i,j}) = \frac{\int_0^T \rho_{i,j}(t)dt}{n_{i,j}} \tag{1}$$

Where $S_{i,j}$ denotes the length of separation time between node i and node j. T is the total time elapsed. $n_{i,j}$ represents disconnection times of two nodes, $\rho_{i,j}(t)$ indicates whether two nodes are in the state of separation.

$$\begin{cases} \rho_{i,j}(t) = 1 \text{ When node i and j are not in communication range of each other} \\ \rho_{i,j}(t) = 0 \text{ When node i and j are in communication range of each other} \end{cases}$$

The smaller the value of $AVG(S_{i,j})$, the lower is the communication delay between node i and j. We take Gaussian similarity function to normalize the value of $AVG(S_{i,j})$, as shown in Formula 2, to denote the association closeness degree between the nodes.

$$R_{i,j} = e^{-\frac{(AVG(S_{i,j}))^2}{2\sigma^2}} \tag{2}$$

Where σ is a scaling parameter of the separation time interval between nodes [9].

The fluctuation of the separation periods between nodes will result in a negligible impact on the communication between nodes. If two cases have the same average separation periods, one fluctuates greatly, and the other fluctuates less, then in the situation of less fluctuation, nodes have good predictability for separation between nodes, so it is more suitable for communication between nodes. We use irregular scale $I_{i,j}$ to measure the fluctuation of such separation period.

$$I_{i,j} = VAR(S_{i,j}) = \frac{\sum_{l} (D_l - AVG(S_{i,j}))^2}{n_{i,j}} \tag{3}$$

Where D_l represents the length of each separation period.

We model the neighbor graph of node in opportunistic network as G = (V, E), where V is the set of nodes, E is the set of edges which connects nodes in the network. Every edge < i, j > in E represents the closeness degree between node i and node j, we use a weight value $W_{i,j}$ to denote it. Because $(R_{i,j}, I_{i,j})$ may represent the closeness degree between nodes, so we let

$$W_{i,j} = R_{i,j} - \alpha I_{i,j} \tag{4}$$

Where α is irregular fluctuations impact factor, its value should be small enough. The bigger the fluctuation of nodes separation periods, the greater is the negative impact on the closeness between nodes. We use Newman's weightiness network analysis algorithm [10] to make community division, and let relationship matrix composed with $W_{i,j}$ be the input of the algorithm, then divide all nodes in opportunistic network into different community.

Definition 1: Destination Community: the community which destination node of message belongs to is called the destination community of the message.

4 Community-Based Adaptive Buffer Management Strategy in Opportunistic Network

CAMBS strategy consists of two parts: the discard strategy and transmitting scheduling strategy of buffered messages. We discuss them respectively as following:

4.1 Community-Based Message Discarding Strategy

To reduce message transmission delay and optimize network performance, CABMS strategy discards messages based on the community property of nodes: When the node buffer overflowing, it drops messages which have not yet entered the destination community firstly. Then for same type messages, they are sorted by the value of $W_{i,j}$ which represents the closeness degree of the node i and destination node j. The message which has smaller $W_{i,j}$ value will be discarded from node i preferentially.

4.2 Adaptive Lightweight Clearance Mechanism for Redundant Copy

In order to improve the successful rate of message delivery in opportunistic network, it always produces multiple copies of message when delivering message. So when messages have successfully reached their destination nodes, a large number of copies of these messages still exist in the networks, which occupy much network buffer space. And these copies will still be spread in the network, which leads to a serious drain on network resources and affect the performance of network seriously. Therefore, we present an adaptive lightweight clearance mechanism for these unnecessary redundant copies. According to the message delivery status, the mechanism can generate delivery status beacon for the message adaptively. By exchanging these beacons among nodes, it can clear these unnecessary redundant copies in distributed way. The detailed method is described as follows:

When a message enters its destination community or reaches its destination node, the mechanism will both generate a delivery status beacon for the message, which specific format is shown in Table 1:

Table 1. Message delivery status beacon

32bit	1bit	7bit
Message ID	Reaching Flag	TTL

Where the reaching flag is used to distinguish delivery status of message: If a message has reached its destination node, the value is set to 1, if the message has just entered its destination community; the value is set to 0. TTL is the maximum number of hops that the delivery status beacon may be spread. According to the small-world theory, it is not more than six intervals for any two people to get connection in social network, so we set the TTL value to be 6 jumps.

When a message enters its destination community, the first receiving node will generate a status beacon for the message. All the nodes, which receive the status beacon and don't belong to such destination community, will clear the copy of the message in their buffer. Then it can reduce buffer occupancy and avoid the message to spread unnecessarily outside the destination community again.

When a message has been successfully delivered to its destination node, the destination node will generate a delivery status beacon for the message again. All other nodes which receive the beacon, will remove the redundant copies of the message to reduce the buffer occupancy and avoid the message to spread unnecessarily throughout the network again, thereby reduce network resource consumption, and it's helpful to improve the transmission performance.

When two nodes meet in opportunistic network, they'll exchange summary vector of buffered messages, and the message delivery status beacons are packed with summary vector and exchanged together. Nodes will handle the delivery status beacon firstly to remove unnecessary copy of messages.

Compared with a normal message, the size of its delivery status beacon is very small, and beacons lifetime has been restricted by their TTL value. Every time beacons are transmitted, their TTL value are decrease by one, when the value is 0, the beacon is cleared. So the spreading of message delivery status beacon list in the network consumes very little network resources. And simulation result shows that its negative affecting to network performance can be negligible.

4.3 Adaptive Message Transmission Scheduling Strategy

In order to let messages be delivered to their destination community and then to their destination node as soon as possible, we propose an adaptive buffer message transmission scheduling strategy based on the community that nodes belong to.

When node i meets node j and wants to send messages to it, node i will sort the sending messages adaptively based on relevant community information, and then make a schedule to decide messages sending sequence which described as follows:

1. Node i sends messages which destination node is node j firstly;
2. If a message has not yet entered its destination community, and node j belongs to the destination community, such message is send secondly;
3. Then, node i sends messages, which have entered their destination community, preferentially to ensure that these messages reach their destination nodes as soon as possible;
4. Furthermore, node i transmissions messages which have not entered their destination community;
5. Same type messages are sorted and scheduled as follows: For messages which are same type, they are sorted by their closeness degree value $W_{i,d}$, where node i is the receiving node and node d is the destination node of messages. Messages which have bigger value of $W_{i,d}$, will be send priority.

5 Simulation and Analysis

5.1 Simulation Environment

This paper selects a datasets collected in real environment to study the buffer management strategy in community-based opportunistic network. This dataset comes from the Infocom 2006 conference project which is a subproject of Cambridge Haggle project [11]. The project has 98 Imote nodes, which use Bluetooth technology to communicate with each other. 20 of which are fixed nodes deployed in different parts of the venue and act as access points, 78 nodes are distributed to volunteers participating in the conference. Such experiment carries out total time of three days; the Bluetooth devices make a scan every 120 s to discovery neighbors.

5.2 Simulation Result and Analysis

In this paper, we use the ONE platform which is an opportunistic network simulation environment, to verify the performance of the CABMS strategy, and compare it with some other typical buffer management strategies such as Drop Front strategy, Drop Oldest strategy, and HBD strategy. We import the real dataset of Infocom 2006 into the ONE platform and make the following experimental model validation based on epidemic forwarding mechanism, where the first 20 % experimental time is the warm-up time of the network, so that nodes can collect some meeting historical data to make community division. After the warm-up time, we assume that each node has known the communities that all other nodes belong to.

1. Comparative analysis of delivery ratio with different buffer sizes. As shown in Fig. 2, with the increase of node buffer size, the possibility of message discarded due to buffer overflow degreases, and delivery ratios are all improved in all four kinds of buffer management strategies. Since CABMS strategy takes advantage of the characteristics of community of nodes movement, and it generates message delivery status beacon to clear redundant messages, when message enters its destination community and reaches its destination node, so the possibility of node buffer overflow is greatly reduced, and the utilization rate of buffer is increased conspicuously. Thereby it can greatly reduce the possibility of useful message discarded. At the same time, CABMS strategy optimizes the schedule of messages sending based on community property of nodes, so the message delivery ratio is improved significantly compared with other three buffer strategies. The delivery ratio of HBD strategy is better than that of DO and DF strategy for it makes message replacement according to the number of message copies in the network. DF strategy only drops messages in the front of the queue, which may result in the loss of some messages in their distribution phase, so DF strategy has the lowest delivery ratio.

   As we can know from the statistical analysis result, the delivery ratio of CABMS strategy can outperforms the second-best HBD strategy by approximately 18.9 % averagely.
2. Comparative analysis of average network overhead with different buffer sizes. As shown in Fig. 3, with the increase of buffer space, the message delivery success rate increases, and the number of messages being successfully delivered to the destination node also increases, which makes the average network overhead all decrease for all four strategy. When message enters its destination community and reaches its destination node, the CABMS strategy generates delivery status beacon for message to clear its redundant copies, and avoids a lot of unnecessary message forwarding, so the messages forwarding times of CABMS strategy is far less than that of other three strategies, and its average network overhead is average only 48.6 %, 40.5 % and 37.9 % compared to that of HBD, DO and DF strategy respectively.

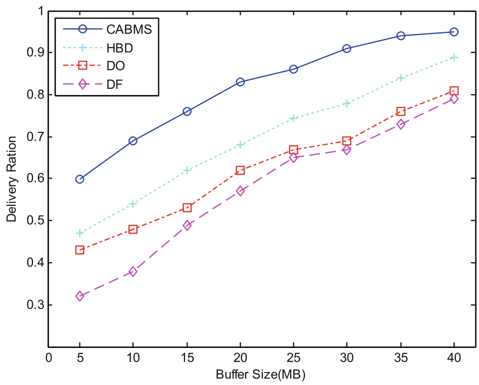

Fig. 2. Delivery ratio against buffer size

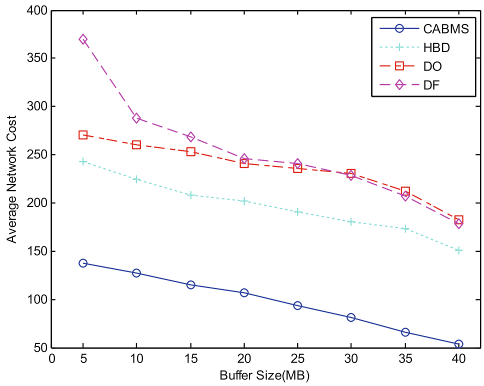

Fig. 3. Average network cost against buffer size

3. Comparative analysis of delivery ratio with different network load. As shown in Fig. 4, with the increase of message generation rate, network load increases gradually, and the probability of node buffer overflow increases either, which leads to packet loss rate increases and message delivery ratio decrease correspondingly. Especially, the delivery ratio decrease relatively larger in HBD, DO and DF strategy than that of CABMS strategy. For CABMS strategy takes a lightweight clearance mechanism for redundant messages copies, it drops unnecessary copies of messages timely and reduces the pressure on the node buffer greatly. Furthermore, CABMS strategy takes community-based optimal scheduling when sending messages, it is helpful to improve message delivery ratio, and thereby the decrease of its delivery ratio is much slower than that of other three strategies when message generation rate increases. The delivery ratio of CABMS strategy can outperforms the second-best HBD strategy by approximately 21.9 % averagely.

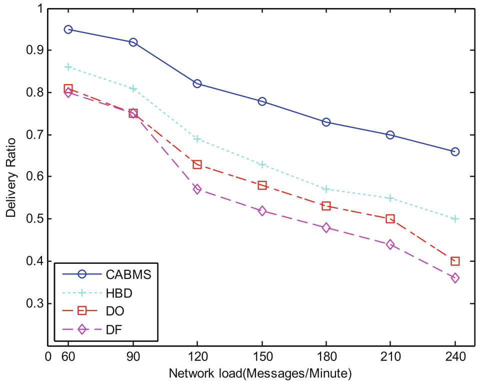

Fig. 4. Delivery ratio against network load

4. Comparative analysis of average network overhead with different network load. As shown in Fig. 5, with the increase of network load, the probability of nodes buffer overflow increases gradually, which leads to packet loss rate increasing. So the average network overhead of all four strategies increases gradually, while the increase of that of CABMS strategy is relatively slower. Since CABMS strategy generates delivery status beacon for message to clear redundant copies of message twice when the message enters its destination community and reaches its destination node, which greatly reduces the probability of nodes buffer overflow and avoids many unnecessary message transmission, thereby increases the probability of successful message delivery.

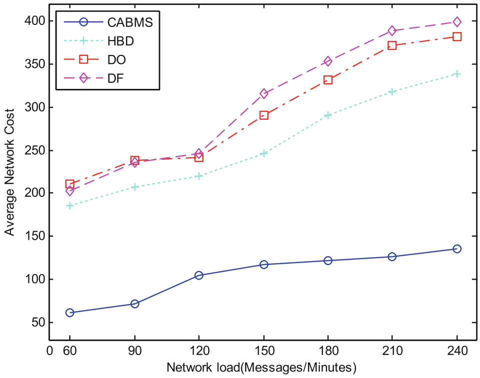

Fig. 5. Average network cost against network load

As we can know from the statistical analysis result, the average network overhead of CABMS strategy is averagely only 40.6 %, 35.6 % and 34.4 % of that of HBD, DO and DF strategy respectively.

6 Conclusion

Networks composed of devices, which are carried by people and have short-range wireless communications capabilities, is a major application scenarios in opportunistic network, whose nodes movement has the characteristics of community. In this paper, we present a community-based adaptive buffer management strategy for such network. When message enters its destination community or reaches its destination node, the CABMS strategy will generate delivery status beacon adaptively for the message to clear its unnecessary copies, which decreases the possibility of nodes buffer overflow greatly and avoid much unnecessary transmission of redundant copies. At the same time, the CABMS strategy optimizes the dropping strategy and the sending sequence of buffered messages adaptively according to the community attribute of nodes, which reduces messages delivery latency and helps to improve the success rate of message delivery. The simulation based on dataset from real environment shows that the CABMS strategy can improve message delivery ratio, reduce average delivery delay and network overhead effectively in community-based opportunistic networks.

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