Routing Strategy Based on Local Density Sensing in Delay Tolerant Network

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Abstract—Aiming at the interval connectivity and the limitation of available storage and internodes throughput in delay tolerant network, this paper designs a kind of Density-Aware Routing Scheme (DARS) for its messaging service. According to the density of nodes, the direction that messages are forwarded to the dense area is decided. The change of correlation time between networks is used to evaluate local density and decide how to exchange information with a certain node met in the process of moving. Simulation results show that the proposed scheme has simplicity and low complexity. In the delay tolerant network of non-uniform node distribution, the message transfer rate and communication overhead get fairly good effect.

Index Terms—Router; Delay Tolerant Network; Messaging; Correlation Time

I. INTRODUCTION

Under the environment of MANET [1] [2], without the support of wireless devices, mobile nodes can be directly connected with adjacent nodes and distribute and exchange the data that they carry in the process of moving data. By any particular routing protocol, source node can receive and broadcast the data to intermediate node of the next node and the data is transmitted to any destination node through the per-hop protocol in MANET. There some popular self-organization routing protocols, such as on-demand distance vector routing protocol [3] [4] and dynamic source routing protocol [5]. Assume that there exists complete end-to-end path between arbitrary sources and destination nodes. First, the AODV and DSR are adopted to determine a complete routing, and then forward data. However, in the DTN [6] in the absence of instant end-to-end path, the assumptions may be vulnerable. In the DNT, obvious transfer delay and interruption will cause the destruction of the network topology. The reason includes topography, around obstacles, the exhaustion of batteries, limited transmission distance, unreliable wireless link and terminal mobility. Therefore, even if the traditional storage-transmit router protocol is common in traditional computer network and MANET, it is not wise to use it. The design of DTN must solve the problems of intermittent connection, long transmission delay and low transmission rate.

The DTR in most literatures is the probability that the copies of the copy message deliver to the destination node successfully as the maximized messages [7] [8]. This section will divide the copies of the routing protocols into two classes: the routing schemes based on flooding and based on quotas. For the conditions whether the routes are based on historical information or not, each route can be further decomposed into two sub directory. Popular routing scheme is a kind of typical scheme based on flooding and the scheme doesn’t need history information. Mobile nodes transmit their storage messages to any neighbor nodes that don’t receive this information. Although the transfer rate is higher, the transmission models lead to considerable throughput resource costs between nodes, storage space, energy depletion and message payload. Recent methods use historical information or replication scheme based on the quota to reduce pressure on communication and resource cost. Some routing protocols based on flooding use the advantages of historical information table to record meeting time and frequency of each node. The literature [9] mentions the ProPHET that the two nodes meet and exchange their history table and the message is transmitted to the nodes with a higher probability. In literature [10], MaxProp records complex historical information in the meeting nodes, and then calculates any possible routing cost. Because of the limited internodes throughput, a node should firstly transmit the message with the least cost in the message queue. Then, RAPID [11] designs different effective measures, using the message queue to minimize missed deadline, the average delay, maximum delay and so on. The Spray and Wait routing protocol in literature [13] and the Spray and Focus routing protocol in literature [14] are two typical routing schemes with or without history quota. The SnW protocol may be executed in two stages. In transmission

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stage, a message with quota copies is repeatedly copied to the meeting nodes, and a node does not enter into the waiting stages and carry the message to the destination until the quota is not reduced to one. The transmission stage of SnF is the same as SnW protocol, but in concentrated stage, the only copy of the message will be transmitted to any certain meeting nodes with higher probability according to historical information. There are some delay tolerance schemes using the node density, the copy density [15] [16] or map density. The literature [13] analyzes the overlapping phenomenon of nodes distribution in DTN and proposes a kind of improved SnW protocol whose number of distributed message is proportional to the adjacent node. The literature [14] changes the copy protocol of popular routing protocol. When a node determines that the current copy density is higher than a limit value, it will reduce the probability that the copy message is transmitted to the adjacent nodes so as to reduce communication pressure in the same area. Literature [8] assumes that all nodes have GPS devices, using location aided knowledge to find the routing in DTN. Mobile node can mark the populated area on the map, and then transmit the query message to populated areas and accept the fastest reply.

This paper makes innovation in the following aspects.

1. This paper designs a kind of Density - Aware Routing Scheme (DARS), it can estimate the possible density of adjacent nodes, and sense density in DTN through store-carry-transmit method. In the nearest meeting nodes, each node only records the exact interconnection time between networks arranged in orderly rows. As the changes of the interconnection time between networks, each node can not only sense local density, but decide to move to a sparse or dense area. When two nodes meet, one of nodes can decide whether the information that it carries is transmitted to another node. DARS does not need to include additional history table, because it can be expanded regardless of the number of nodes. DARS only can copy the limited number of message copies in network, which is suitable for the condition that the available storage and internodes throughput are limited in DTN. Simulation results show that in terms of message transfer rate and communication overheads, in the non-uniform node distribution, DARS achieves fairly good performance.

2. This paper tests the essence of adjacent nodes density in effective message transmission of the DTN. Considering the non-uniform node distribution in the geographical scale, in practice, there are sparse and close phenomena in the distribution of node group. For example, the node density in urban areas is higher than that in suburban. Ideally, because the interconnection time between two consecutive meeting nodes in the dense area is shorter than that in sparse area, the nodes in the DTN should be able to send message to the meeting nodes in dense area. In this way, nodes can quickly distribute message in DTN, which reduces the transmission delay and improves the information transmission rate.

3. The proposed DARS in this paper uses node density to decide the direction of dense area to which the message transmits. DARS only depends on the change of interconnection time to assess the local density and it does not need any positioning equipment or history information of adjacent nodes. DARS and literature [14] have some similarities, but DARS can restrict the message traffic to prevent point from loading cache. Besides, the DARS does not need to compute the history table about the possibility that reach the destination nodes in literature [14].

II. SYSTEM MODEL

As shown in figure 1, the store-carry-transmit method is a good design that the data makes movement incrementally and storage in network, and finally the data reaches their destination nodes. Predecessors put forward a lot of delay tolerant routing technology, including the technology based on backup, based on history, based on positioning, and based on coding technology. In particular, the technology based on the backup tries to increase transmission rate and reduce the transmission time through maximizing unarranged transmission opportunities. Only when the network provides a large number of local storage and internodes bandwidth, relative to situation of forecasting message flow and waste of resources, the technology is feasible. The technology based on the history needs the nodes to the frequency of meeting save node additionally. This information will be forward to the next destination node with a relatively high probability [7] [8] [9] [10], but when the number of nodes is great, the technology will cause a large amount of calculation and maintain overhead. For the technology based on location [11], its work is based on a weak commitment, namely all of the nodes has a specific positioning capabilities, such as GPS. Finally, some researches examine the use of specific coding technology in the DTN such as erasure coding and network coding, rather than the development of any delay tolerant algorithm itself.

Figure 2 shows the DTN environment composed of m mobile nodes and each mobile node $N_i$ has the ability of communication, storage, and following the store-carry-transmit routing rules. Assuming that all nodes have the same transmission distance, when a node moves to another node's transmission range, the two nodes can find each other. The adjacent nodes or meeting nodes are called $N_e$ in the next section. In DTN, when
nodes meet \( N_i \), the message in the cache is transmitted. Then, the nodes carry the message in the cache to transmit in the network. In this way, certain source node \( N_i \) can transmit messages to the intermediate node \( N_j \), and then the messages that it carries are transmitted to the next node until it meets the destination node \( N_d \). Here are some basic parameters in the environment of DTN. First of all, \( N_i \) can directly connect with \( N_j \) within the transmission range \( R \). Second, the transmission bandwidth \( W \) represents the data throughput between \( N_i \) and \( N_j \). Third, the cache size of \( N_j \) is \( B \) and the cache can carry and store the message copy with the size of \( B \) which is sent by other nodes. At last, mobile mode decides the target path of nodes and the speed in the next environment, such as mobile track within a time series. Normally, mobile model is based on a mathematical model, such as the Random Waypoint and Random direction. This paper uses the model to generate the movement trajectory of a 2D map.

DTR designs that which nodes the message copy should be sent to. A message copy at least includes the row identifier, source nodes, and target nodes. Time - to - Live (TTL), message size, options and effective payload. When TTL reduces to 0, messages will be automatically discarded. Message size represents the needed minimum transmission throughput and cache in the process of meeting.

System model uses two assumptions. First, \( N_i \) records the orderly sequence of interconnection time, such as \( I_1^i, I_2^i, \ldots, I_n^i \), which is one-to-one correspondence to the meeting \( \alpha \) nodes. Figure 3 describes orderly sequence \( I_0^i, I_1^i, I_2^i \) of a time range. \( I_1^i = t_3 - t_1 \) represents the latest interconnection time of N1 and N2 in the time of t1 and t2. Similarly, \( I_2^i = t_5 - t_3 \) represents the previous interconnection time. \( I_0^i \) represents the latest meeting time until now. As a result, each node only manages a continuous interconnection time series, which does not consider the meeting nodes and the number of nodes in the system.

III. LOCAL DENSITY ROUTING POLICY

DARS design includes four phases, as shown in figure 4. (1) Interconnection time standardization eliminates the computed interconnection time deviation caused by the change of node speed. (2) Density estimation considers a series of the latest \( \alpha \) meeting times to estimate the density of the adjacent areas, integrated the node's value to improve the valuation accuracy. (3) The edge detection along the track of mobile node seeks the edge of the dense area and sparse area to determine whether a node is moved to the area of sparse or dense area. (4) Forwarding strategy determines the number of message copies, message forwarding protocol and message transmission priority in cache. Then, the specific mechanism is introduced.

A. Interconnection Time Formula

DARS uses consecutive interconnection time to estimate the surrounding node density to instead of the number of adjacent nodes in a MANET. Density estimation evaluation methods assume that if its interconnection time is less than the set limit \( T \), nodes will be moving to a dense area. However, in order to reduce the possibility that the nodes encounter many nodes in a short time, this method sets the interconnection time to \( I_1^i, I_2^i, \ldots, I_n^i \). The setting of \( \alpha \) affects the sensitivity of density estimation, because \( \alpha \) represents the round-trip length of \( I_n^i \) in front of \( N_i \). When \( \alpha \) is equal with one, a node could judge the local condition wrongly. As \( \alpha \rightarrow \infty \), \( T_i \) represents the historical average. Therefore, a node uses \( T_i^\alpha \) to represent its closely average interconnection time. For example, in the figure 3, \( \alpha = 3 \). When \( N_i \) meets another node, update

\[
\tilde{T}_i = \frac{I_1^i + I_2^i + I_3^i}{3}.
\]

This method still has to consider that \( N_i \) does not meet any nodes within a certain time. The time is longer than the last average interconnection time, which is called \( \tilde{T}_i \). In the condition that \( I_0^i > \tilde{T}_i \), this method updates the measurement of specific value \( I_0^\alpha \).

\[
I_0^\alpha = I_0^i + I_1^i + \ldots + I_0^{\alpha-1} = \frac{\sum_{k=0}^{\alpha-1} I_k^i}{\alpha}
\]
Using $I_p$ is to ensure the update of local information when $I_p > \bar{I}$. Because $N_i$ can’t exactly predict the time that it meets another node, when $N_i$ has experienced a long-time transmission but it doesn’t meet any nodes, the $I_p$ is used to instead of $\bar{T}_i$ and the density of sensor nodes can change. Especially, when $N_i$ meets another node, $I_p$ is marked as $I'$ and $\bar{T}_i$ is equal with $I_p$.

### B. Standardized Interconnection Time

Considering that the nodes have different movement speed and they stops in different time, their movement affects the evaluation of dynamic network density and intensity. The processing of the change of interconnection time is necessary to improve the accuracy. Literature [11] researches random path points, random direction and the mobile mode based on community. This model is suitable for mobile assisted routing protocol in DTN.

The design points out the connection between the average interconnection time and the average speed which is shown in the formula of the enhanced RWP mobile model in literature [11].

$$E[I]_{mp} = \frac{1}{p_m \bar{v}_{mp} + 2(1-p_m)} \cdot \frac{A}{2RL} \bar{T}_{stop}$$

(3)

$ar{T}$ is the average time quantum in every movement process and $\bar{T}_{stop}$ is the average stopping time of every movement. $A$ is the size of network area and $R$ is the transmission arrangement and $\bar{v}$ is the average distance between two positions. $\bar{v}_{mp} \approx 1.75$ is the standardized relative speed in RWP and $p_m = \frac{\bar{T}}{\bar{T} + \bar{T}_{stop}}$ is the possibility that the nodes move in any certain time.

Supposing $T_{mp} = c \times \bar{T}$, $p_m = \frac{1}{1+c}$, and $c$ is a constant, the above formula can be represented as the follows.

$$E[I]_{mp} = \frac{1}{p_m (\bar{v}_{mp} - 2) + 2} \frac{(1+c)A}{2R} \bar{T} \frac{1}{L} = K \frac{1}{v}$$

(4)

In this formula, $K$ is a constant.

In the formula (4), $E[I]_{mp}$ and $\bar{v}$ are in inverse proportion. In order to reduce the valuation deviation caused by changes in the rate of nodes, the standardized interconnection time $I'$ is used to instead of $I$, which is realized through a relative parameter of average speed and the current speed. Therefore, the formula (5) obeys that the density estimation only suffers the influence of node density.

$$I' = I \cdot \frac{v}{\bar{v}}$$

(5)

### C. The Closely Density Estimation

According to the standardized results of formula (1) and formula (2), this method generates a measurement function $D_i(t)$ within a certain time and it makes the strength within the numerical interval $[0,1]$.

$$D_i(t) = \begin{cases} 
0, & I_i > 2\bar{I}, \text{and } I_i^0 < \bar{I}_i, \\
1 - \frac{I_i^a - I_i^0}{2\bar{I}}, & I_i < 2\bar{I}, \text{and } I_i^0 < \bar{I}_i, \\
0, & I_i > 2\bar{I}, \text{and } I_i^0 \geq \bar{I}_i, \\
1 - \frac{I_i^a - I_i^0}{2\bar{I}}, & I_i < 2\bar{I}, \text{and } I_i^0 \geq \bar{I}_i, 
\end{cases}$$

(6)

As the increase of value, the density and strength is higher. Mid-value ($D_i(t) = 0.5$) is used to distinguish between the high strength and the low strength. Therefore, the double $\bar{I}_i$ is the maximum boundary value in decisive comparison. Because $I_i^a$ or $\bar{I}_i$ is larger than $2\bar{I}_i$, the density strength is set as zero. Otherwise, when the node $N_i$ moves to dense area, the value of $\bar{I}_i$ will become smaller and $D_i(t)$ will become bigger. When $N_i$ keeps ($I_i^0 \geq \bar{I}_i$) for long time and it does not meet any other nodes, the value of $I_i^a$ decreases along with every $\bar{I}_i$.

In addition, this method considers movement factor and develops a kind of increment density estimation method to enhance assessment. This assessment protocol allows a node to get more information of the surrounding meeting nodes so as to strengthen the assessment of regional node density. In order to simplify the calculation, this method will average evaluated value of two meeting nodes to generate the value-added assessment.

$$\bar{D}_i(t) = \frac{D_i(t)+D_i(t)}{2}$$

(7)

$D_i(t)$, $\bar{D}_i(t)$ respectively represents the evaluated values of self perception and meeting nodes.

### D. Boundary Detection

Boundary detection method is density estimation error based on comparative baseline 0.5. According to the formula (6), density strength of the nodes that is near to the edge of the dense and sparse area near a node should be close to 0.5, because the density strength is greater than 0.5 in the dense area and it is less than 0.5 in sparse area. Therefore, this method can solve the problem that which nodes keep message or receive message copy when two nodes meet in the boundary. According to the ascending or descending order change of self perception density strength $D_i(t)$ in the process of movement, $N_i$ can predict whether it moves to dense area or sparse area.
Then, when two nodes meet, they can refer to figure 5 and they can know their own trajectory and determine their meeting point so as to decide to save the message or forward the message copy of movement trajectory.

Figure 5 describes the four conditions when two nodes meet in the boundary. In case (a) and (d), they have the same intensity. For example, the density strength is both greater than or less than 0.5. They don’t transfer the message to avoid unnecessary expenses. Instead, case (b) and (c) describes two nodes with different strength. For example, one node’s strength greater than 0.5 and another is less than 0.5. The nodes that remove from the dense area will forward message copy to the other nodes moving to the dense area. Therefore, the above method is applied to the message forwarding protocol in the network. In the network, the message copy transmits in boundary according to difference of self-perception density value between the two nodes.

![Figure 5. The two nodes meet in the boundary](image)

### E. Message Forwarding

Compared with other protocols, SnW solution has the superiority in terms of cost efficiency and communication load, the proposed message forwarding mechanism extends the basic SnW scheme. The joint of density of perception improves routing performance in DTN. This mechanism has two stages, the binary forwarding stage and waiting stage, which is as shown in figure 6.

![Figure 6. The binary transmission model](image)

Binary forwarding stage: the source nodes of the message firstly begin with a copy quota of M message copies. When any nodes (source nodes or relay nodes) are more than a message copy (n > 1) and it meets with the nodes without copies, a half of message copy is forwarded to the other nodes and it reserves another half of message copy. When a node has only one copy, it is switched to the waiting stage.

Waiting stage: when any node has only one message copy, it implements an active forwarding decision based on close density value and boundary detection information. When two nodes meet, the messages should be carried by the nodes that have already moved or are moving to dense area. This method is different from the original SnW model, any nodes of the original model in waiting stage does not forward the last message copy until it reaches the destination node.

In additional, DARS considers the possibility that the distributed number of message copy affects the successful transmission of message to destination nodes. DARS, therefore, gives priority to the message in queue and speeds up the transfer rate through the following steps. Assume that the two nodes $N_i$ and $N_j$ meet in the transmission range. First, $N_i$ sends message in the forwarding stage. Second, when $N_i$ has several messages in forwarding stage, choose the message that $N_j$ does not own at present. Third, in the condition that there are several messages, choose the message with the most message copies. Forth, when $N_i$ has several messages in waiting stage and $N_j$ has already moved to or is moving to the sparse area, $N_j$ forward this message to $N_i$. At last, only if the rest of node bandwidth of $N_i$ and $N_j$ is enough during the period of meeting, $N_i$ can transmit another message according to the above steps.

### IV. PERFORMANCE EVALUATION

#### A. Experiment Environment

The simulation experiment uses the simulation platform of ONE and this platform uses a DTN route based on the developed RWP mobile mode. For this model, the possibility that the nodes move the specific position is fixed. The simulation environment contains n nodes ($n=300$) and the area is $2400 \times 2000 m^2$. The moved speed of every node is $v = 0.5 \sim 2.5 m/s$. For the next path point, the possibility $p = 0.1 \sim 0.9$ is that this node moves to the central area with the size of $2400 \times 2000 / d^2$ ($d = 4$ is an adjustment parameter). The simulator creates a transport request packet every 50 seconds and all of the size of the package is 1KB, and then they are not thrown away until they are more than the life cycle (9000s). In the process of moving, the mutual transfer rate of any two nodes is 250 KB and transmission range is $R$ ($R$ is equal with 10m). They exchange the copy of packet that has not been received. Each package has the same copy quota of message copy (m=8) and the cache of each node is 5 MB. If node cache overflows, it will not receive any package. Therefore, in order to simplify the calculation, the cache isn’t used to replace strategy. The emulators with the above settings run to 345600 s in total and send 5912 packets.

#### B. The Experiment Results and the Analysis

The relative performance of DARS and SnW is tested through setting $\alpha = 1 \sim 6$ and probability $p = 0.1 \sim 0.9$. When $p$ increases from 0.1 to 0.4-0.9, the grown
transmission rate can reach its maximum value, but when $p$ is more than 0.7, the performance began to decline. When $p$ is higher, more nodes will be gathered in a central sparse area with the smaller density evaluation error, so the influence of boundary detection is not obvious. On the other hand, the same $p$ is given and as the increase of $\alpha$, the transmission rate increases. When $\alpha=3\sim5$, the results are similar, but in most cases, when $\alpha=4$, the transmission rate arrives at the peak. When $\alpha$ is greater than 5, the transmission rate can be reduced to a minor, which is cause by the reason that a longer length of back and forth movement can reduce the sensitivity of the density value. DARS, therefore, can show the better performance in the non-uniform nodes distribution ($p=0.4 \sim 0.7$) and the specific back and forth distance $\alpha=4$.

When the network has a variety of dense areas, compared with SnW, DARS has a higher transmission rate in all cases. However, when the number of dense area increases, the transmission rate will drop sharply. This kind of situation can be interpreted as a large number of dense areas reducing the number of nodes in each area and the closely density of nodes.

![Number of nodes vs transmission rate](image1)

**Figure 7.** The transmission rate of different number of nodes

![Number of nodes vs communication load](image2)

**Figure 8.** The communication overhead of the different number of nodes ($y$ is the number of copies of every original message)

Simulation results further investigates the transmission rate of different number of nodes and the performance of the communication overhead. Figure 7 and figure 8 is in the center of a dense area and $\alpha=0.4, p=0.6, m=8, n=100 \sim 1000$. It is observed from SnW and DARS that a large number of nodes increases the transmission rate. With the increase of number of nodes, DARS improves the self-perception from more node information and the precision of the density value. Then, a node can improve the boundary detection and decide to forward message copy to the appropriate relay nodes. In contrast, because in waiting stage, the nodes in SnW continue to keep message copy and the transmission rate of SnW is still lower than the average 8.4% of the DARS. Therefore, the increase of node number is helpful to keep the reliability of increasing density value and the detection of border area.

On the other hand, compared with SnW, DARS has higher communication overhead. This can be understood that in the waiting stage, the nodes of DARS still attempt to transmit message copy to any nodes that are more likely to be close to dense area. By contrast, SnW restricts that the total copy of every original can’t be more than the copy quota.

V. CONCLUSION

Aiming at the limit of intermittent connectivity, available storage, internodes throughput and the others in DTN, this paper designs a kind of density sensing routing scheme for its messaging service, which allows the self-perception of moving nodes for the change of the closely node’s density and detects boundary between dense area and sparse area and decides the place and the time that the message copy is forwarded to the meeting nodes in the process of moving. The simulation experiment compares the DARS and SnW performance and the experimental results show that compared with SnW, DARS has better performance, which mainly reflects message transmission rate and communication overhead in the non-uniform node distribution. For DARS, non-uniform node distribution and the node number are two favorable factors, but at the same time, the communication overhead of DARS remains to expand.

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