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Design of Routing Protocol for Opportunistic Network Based on Adaptive Motion

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ABSTRACT Opportunistic network takes advantage of the contact opportunities introduced by node movement for data transmission. Data is usually piggybacked during the movement of the carrier, which guarantees its independence, however, the system performance is impaired. Inspired from the motion nature of nodes, this paper proposes an adaptive motion based opportunistic routing protocol to address the problem. It develops a data forwarding priority model from the perspective of data communication and determines data transmission rules in combination with node activity range partition scheme. A differential replica transfer strategy is thus proposed to achieve a tradeoff between transmission efficiency and system overhead. A free motion degree model is constructed based on which a utility function is deduced to choose appropriate nodes for data relaying. The simulation results show that the proposed algorithm achieves higher packet delivery ratio and less transmission latency while satisfying application requirements and restraining network overhead.

INDEX TERMS Data forwarding priority, free motion degree, opportunistic routing, utility function, activity range partition.

I. INTRODUCTION

Opportunistic network is a self-organized network which exploits the opportunities created by node movement to transmit data under the circumstance of intermittent communication links [1]. As an emerging technology, it faces many challenges that have not been encountered in traditional networks, of which the packet delivery problem attracts great attention of researchers [2]–[4]. Due to its intermittent connectivity, data has to be stored until an appropriate relaying node is found. The opportunistic network routing mechanism is based on the intermittent connections between nodes and makes use of the contact opportunities introduced by node movement to forward data [5], [6]. Before the next hop is found, data has to be carried, waiting to be delivered. Based on this message transmission strategy, opportunistic network routing protocols can be divided into three categories: replica based routing, active move based routing and utility based routing.

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- Replica Based Routing
  Replica based routing strategy improves its delivery efficiency by producing a certain number of copies in network [7]. It can be divided further into single copy version and multi copy version. Direct Transmission (DT) protocol [8] belongs to single copy version. In DT, the source node carries messages until it encounters the target node. Each packet is transmitted only once with no further copies pouring into the network. It achieves the smallest network overhead at the cost of large packet delay and low delivery efficiency. The multi copy version is originated from flooding policy and can be further classified into full network flooding and partial network flooding. Epidemic Routing [9] adopts full network flooding which maintains a summary vector for each node to store its local messages. New information is acquired through summary vector exchanging when nodes meet. Packet spreads promptly over the whole network in flooding mode and finally reaches the destination. Epidemic Routing can find the shortest path to the target in a fully connected network to achieve a lower delay if provided with sufficient resources, however,

it produces a lot of redundancy which incurs huge overhead to the whole network. 2-Hop [8] algorithm utilizes partial network flooding to deliver copies to the first n neighbors that encountered to limit the transmission range within 2-hop radius to avoid redundancy. Spray & Wait [10] also adopts partial network flooding strategy in which the source node defines the maximum number of packets that can be forwarded in Spray phase. Each node receiving the copy forwards the packet with a certain proportion. Once the copy number is decreased to 1, node enters into Wait phase to carry the message copy until it meets the target node eventually.

- Active Move Based Routing
  In active move based routing, special nodes that are capable of active move are introduced to serve the communication between other terminals. DataMULEs [11] introduces MULE node to collect data from sensor nodes during its movement in sparse network environment. Message Ferrying [12] deploys ferrying nodes in some regions to move according to predefined paths or demands from ordinary nodes to improve system reliability and transmission efficiency.
- Utility Based Routing
  The utility based routing strategy selects an appropriate next hop to avoid blindly forwarding by introducing utility value evaluation. Inspired from social network analysis, PQBCF [13] designs a metric of betweenness centrality to estimate the active degree of nodes and chooses nodes with greater value as relays to increase query success rate while reducing query latency. Zhao *et al.* [14] proposes a differentiated scheme to assign different nodes with different forwarding probabilities based on their respective energy to guarantee energy balance and prolong the lifetime of network. EECDR [15] takes both the message spreading degree and node residual energy into consideration and then develops an energy efficient copy distributing status aware routing mechanism, which is based on encounter probability predicting method to find the appropriate relaying nodes. EEOR-FL [16] is designed to calculate the list of forwarding candidates to address the problem of energy balancing to minimize energy consumption and increase lifetime of network. In SMART [17], each node builds its own social map consisting of nodes it has met and its frequently encountered nodes in distributed manner. Based on both encountering frequency and social closeness of two linked nodes in social map, it decides the weight of each link to reflect the packet delivery probability between these two nodes. Xu *et al.* [18] investigates the problem of opportunistic routing based on the dynamic social relationship and proposes a new prediction method to predict the movement pattern and the encounter time. PeopleRank [19] protocol is originated from classical PageRank algorithm and it calculates the node centrality in distributed way to reduce the complexity of traditional social network analysis. BUBBLE [20] algorithm considers social position of nodes and uses node community and centrality information to forward data. In EBOR [21] the source node considers both residual energy and packet delivery probability as evidence to determine an optimal next hop in underwater acoustic sensor networks. With trust-based computation, the number of neighbors participating in forwarding is optimized to reduce energy consumption. LORA [22] uses a prioritization metric to select a set of candidates as potential forwarders and it is designed to restrict the number of candidates which wake up simultaneously and to counterbalance between the waiting time problem and the duplicate packets problem for asynchronous duty-cycled wireless sensor networks. EITSA [23] divides social communities according to nodes characteristics and it allows information to be transmitted between resource nodes and social communities to achieve good performance with nodes that extend network lifetime and reduce energy consumption in social communication environment. ICPP [24] proposes a method that characteristic interests with neighbors are selected or pushed by users. According to interest characteristic probability predicted method, interest neighbors can be selected and receive or send information. SCOR [25] exploits context information of network to predict the mobility patterns of nodes based on Back-Propagation neural networks model. To address the problems of unfair traffic distribution and unfair delivery success ratio, FSMF [26] introduces a Markov chain model of users' social ties to evaluate users' social relationship, it then limits the number of message copies and restricts the number of forwarding copies according to users' social ties to improve fairness. ICMT [27] identifies surrounding neighbors to evaluate nodes between delivery probability, which caches data distribution adjustment, ensures the high delivery probability of node preferential access to information and achieves the objectives of cache adjustment. FCNS [28] exploits comprehensive node similarity for opportunistic social networks. It determines the transmission preference through fuzzy evaluation of mobile and social similarities and the transmission process is performed through feedback mechanism. TPMEC [29] establishes a transmission prediction mechanism exploiting comprehensive node forwarding capability in opportunistic networks. When quantifying the forwarding capability of nodes, it not only considers the cooperative tendency but also discusses the encounter strength between nodes. It utilizes the theory of matrix decomposition to predict and supplement the missing forwarding capability value of nodes to improve the efficiency of message transmission. Gao and Cao [30] formulates the transient node contact patterns and then develops data forwarding metrics to analytically predict the contact capability of mobile nodes with better accuracy to improve

effectiveness of data forwarding decision. PRoPHET [31] calculates delivery probability for each pair of nodes and the transmission of contact probability is used to update the delivery prediction probability to transfer data from nodes with lower probability to higher ones until the target node is reached.

In above routing algorithms, replica based routing strategy ensures data transmission by producing multiple copies of messages, which incurs a large amount of redundancy into network, resulting in a high demands for network resources and leading to a lot of waste. Active move based routing protocols introduce some special nodes with mobile functions. Such nodes are often equipped with strong motion ability, big storage capacity and powerful communication capability, which are totally different from other ordinary nodes. Moreover, it is supposed that the location of the target node is fixed and the communication between mobile nodes are not considered [32]. And utility based routing strategy exploits encounter prediction, link state, context information etc. to calculate utility value for relaying node selection. It does not fully consider the different requirements of applications and the influence of node's own motion on routing performance.

Data is piggybacked during its carrier's movement in opportunistic network [33]. Node searches for chances to forward data during its free move and its trajectory is immune from the carried packets generally, which guarantees its independence while imposes some adverse impact on data transmission, leading to low delivery ratio and high transmission latency. As we know that the concept of opportunistic network is partially originated from Delay Tolerant Network [34], which emphasizes the delay tolerance of applications. However, with the development of opportunistic network research, more and more different types of traffics are supported and the demands for data transmission are becoming diverse [35]–[37]. We believe that different transmission strategies should be adopted for different communication requirements, especially for those with higher transmission demands. If we depend only on the limited contact opportunities created by random movement to forward data, the diverse requirements of applications can not be satisfied accordingly. In some cases, we think, node should be allowed to sacrifice its motion independence to build a fast and effective connection by adjusting its trajectory adaptively. However, it should be noticed that the change of trajectory will undoubtedly bring some impact on its original task schedule. Therefore it should take both application requirements and task schedule into consideration to design an effective data forwarding strategy for opportunistic network based on the motion characters of nodes.

Since opportunistic network is designed to utilize the contact opportunities introduced by node movement to transmit data [38], it is supposed to take full advantage of the motion characters to serve data transmission better. In this paper, we propose to design a routing algorithm for opportunistic network based on adaptive motion of each node. In section II, we present the detailed description of the proposed algorithm and Section III evaluates the performance of the protocol and Section IV, concludes the paper.

II. DESIGN OF ADAPTIVE MOTION BASED OPPORTUNISTIC ROUTING ALGORITHM

A. DESIGN OF DATA TRANSMIT SCHEME

Data usually experiences two phases on its routing to the destination: relaying phase and direct delivery phase. In order to achieve stable data transmission, it is better to involve less nodes during the process of transmission and direct delivery is usually preferred [39], especially for opportunistic network in which there may not be a complete delivery path between source-and-destination pairs. Under such circumstances, direct delivery method is more reliable. However, the prerequisite for direct delivery is that the data-carrying node can build an immediate connection to the final destination, which is precisely not available in most cases. Due to its Store and Forwarding mode in traditional algorithms, those data carriers, which can not implement direct delivery currently, have to choose a relaying node to forward the data further to the target node. However, the unique Store, Carry and Forwarding method provided by opportunistic network offers us a new option, in which data is carried until it can be directly delivered to the target.

Direct delivery method improves both packet delivery probability and reliability of transmission, but it also incurs some adverse effects, especially when there is no immediate connections that can be constructed between nodes. In such a case, an enforced direct delivery operation will only deteriorate the transmission performance of network. Therefore a new data transmit strategy has to be designed to guide the delivery of data packets.

1) DATA FORWARDING PRIORITY EVALUATION MODEL

In order to adapt to different requirements of applications, a Data Forwarding Priority (DFP) model is built based on the characters of weak connections and intermittent communication of opportunistic network so that the data transmission can match with the scheduling of network resources better. Data forwarding priority is the priority evaluated to determine how data should be forwarded, according to which different forwarding strategies are adopted with different priority values. It can be classified into three levels according to different requirements of applications: Urgent Forwarding, Preferential Forwarding and Normal Forwarding, with decreasing priorities. The factors that affect data forwarding priority include data transmission, data content and application requirements. Data forwarding priority is directly proportional to not only the importance of data content and the priority of nodes involved in transmission, but also the delay requirements of applications. Hence data forwarding priority $P_\gamma(m, s, i)$ is defined as:

$$P_\gamma(m, s, i) = B_m D_m G_\gamma(s, i) \tag{1}$$

where m denotes data, γ represents relaying nodes set from source node s to current node i. B_m, D_m and$G_\gamma(s, i)$ represent content priority, delay priority and node chain priority respectively. Content priority denotes the importance of data from the perspective of information to measure the significance of data itself. It can be divided into Ordinary Information, Important Information and Major Information, with increasing priorities. The information will be evaluated in advance according to its content before transmission to decide its content priority. Delay priority embodies the requirements of applications on transmission latency and can be divided into Best Effort Delivery, Preferred Delivery and Critical Delivery, with urgency increases progressively. Node chain priority represents the priority of relaying nodes involved in data transmission and it covers the whole node chain from source node to current node. So long as important node participates in the relaying process of messages, node chain priority is high, which satisfies:

$$G_\gamma(s, i) = \max_{j \in \gamma} G_j \tag{2}$$

where G_j represents priority of node j.

The general idea for data forwarding is designed as: Direct delivery first for urgent forwarding while maintaining independence for normal forwarding. The motion pattern of nodes is then divided into three different modes: Inherent Move, Active Move and Coordinated Move. In inherent move mode, node remains its original move state irrespective of data that carried to ensure independence. In active move mode, node changes its move state voluntarily to fulfill effective delivery. While in coordinated move mode, node needs to consider both its original task scheduling and the new transmission requirements synthetically to adjust its trajectory.

2) DIFFERENTIAL REPLICA TRANSFER MECHANISM

The opportunistic network usually exploits multi copy transmission strategy to guarantee its delivery probability, which incurs some overhead. Considering the priority requirements of data forwarding, different transmissions have different goals. For urgent forwarding, timely and effective delivery is of the most important concern. While for normal forwarding, system overhead is usually more cared and delivery failure is even sometimes tolerable to a certain extent. Hence a differential replica transfer mechanism is developed based on data forwarding priority:

- For data with low forwarding priorities, a conditional forwarding strategy is resorted to choose appropriate relaying nodes. Data is forwarded in inherent move state, hence the number of copies can be controlled at a lower level to reduce system overhead.
- For data with high forwarding priorities, messages are transmitted by node's movement combined with flooding scheme. On one hand, the data is delivered directly to the target node through the active move of node. On the other hand, flooding scheme is exploited to spread the data to all the nodes that encountered. This parallel transmission method guarantees timely and effective delivery of data.

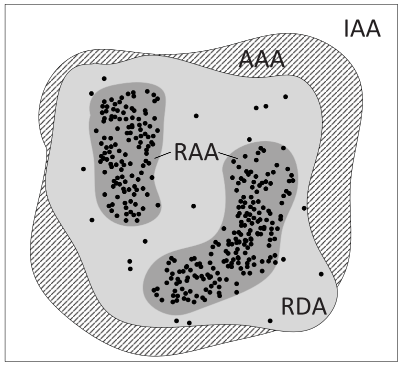


FIGURE 1. **Illustration of node activity range partition.**

- In order to refrain the interference introduced to other transmissions, a Mutex Protection mechanism is proposed for urgent forwarding, which stipulates that only the first node that is not in active move state receiving the data takes active forwarding method, other nodes spread the data and maintain their inherent move state.
- The active move forwarding method can be an effective complement to flooding scheme. It makes up the insufficient coverage problem of flooding in some cases to ensure the delivery of data and further reduces the transmission delay.

3) NODE ACTIVITY RANGE PARTITION

Node dynamically adjusts its trajectory to ensure effective forwarding of high priority data based on its own scheduled tasks and application demands. Considering the complexity of task scheduling and route planning, we introduce node activity range partition scheme to map task scheduling to activity range to simplify the design.

In opportunistic network, data-carrying node searches for forwarding opportunities in its motion state. It is the movement that provides the possibility of data exchanging. The activity range of node can be partitioned into four regions: Routine Access Area (RAA), RanDom Acess Area (RDA), Authorized Access Area (AAA) and InAccessible Area (IAA) as shown in Fig. 1. In this figure, the black dots denote the footprints of nodes, the dark gray area represents routine access area, the light gray area is random access area, the shadow part denotes authorized access area, and the rest is inaccessible area.

As we can see from the figure that the routine access area is the area with the highest visit frequency. When node carries data destined to this area, it can be piggybacked during the visit. Under this situation, no more demands on data forwarding priority are required. Random access area is the area where node will visit occasionally. Due to its randomness, if data is destined to this area, node needs to adjust its route to cater for the delivery, which requires a certain level of data forwarding priority. Authorized access area is the area where node can access but has not visit yet. A higher data forwarding priority is necessary if node is required to change its route

TABLE 1. Data transmission rules.

DFP / Target Area	Urgent Forwarding	Preferential Forwarding	Normal Forwarding
RAA	Direct Delivery/Active Move	Direct Delivery/Inherent Move	Direct Delivery/Inherent Move
RDA	Direct Delivery/Active Move	Direct Delivery/Active Move	Conditional Forwarding/Inherent Move
AAA	Direct Delivery/Active Move	Active Forwarding/Coordinated Move	Conditional Forwarding/Inherent Move
IAA	Active Forwarding/Inherent Move	Conditional Forwarding/Inherent Move	Conditional Forwarding/Inherent Move

to access this area. Inaccessible area denotes the area where node can not visit. Under no circumstances can node visit inaccessible area.

4) DESIGN OF DATA TRANSMISSION RULES

According to diverse distribution of target area and distinct data forwarding priorities, different transmission rules are made as illustrated in Table 1. It shows that, for urgent forwarding, unless the target node is located in inaccessible area, node will actively adjust its route to move towards the destination and deliver data to the target directly. For preferential forwarding, if the target node resides in routine access area, which implies that the probability of building an immediate connection to the target node is high. Given the fact that the transmission requirements of preferential forwarding is not as pressing as urgent forwarding, the direct delivery can be fulfilled by inherent move of node. The transmission delay of preferential forwarding is increased compared to that of urgent forwarding, however, the node's motion state remains unchanged, which guarantees its independence. In case the target node locates in random access area, it is necessary to deliver data directly through active move of node. If the target node resides in the region that the relaying node has never visited before (including authorized access area and inaccessible area), it is necessary to find an appropriate relaying node to forward the data packet further. For normal forwarding with the lowest priority, the region where the target node locates does not affect the data transmission decision, and the node's trajectory will not change, node maintains its original motion state to provide independence.

5) IDENTICAL TARGET DATA PIGGYBACK MECHANISM

Active move forwarding method may cause nodes to gather to the same area as illustrated in Fig. 2. The source node *Src* transfers data to its neighbors *A* and *B* which are both already in active move state. Because of mutex protection mechanism, data can only be spread to node *C*, *D*, *E* and *F* respectively. Node *D* and *F* then switch to active move state and move towards the target area where the destination node *Dst* locates. But node *E* is already in active move state, it only forwards the data to its neighbor *G* which is not in active move state currently. *G* then shifts to active move state and moves towards the target area immediately. Therefore node *D*, *F* and *G*, carrying the same data, gather at the identical area to produce local traffic congestion and waste network resources. Considering the possibility of nodes encountering on their way to the same target area, we develop identical target data piggyback mechanism through negotiation between nodes. After negotiation, the node with the higher burden index gives up its current transmission mission and executes its next scheduled task. The chosen one, with the lower burden index, will continue with its ongoing data delivery task. It not only releases network resources but also avoids traffic conflicts.

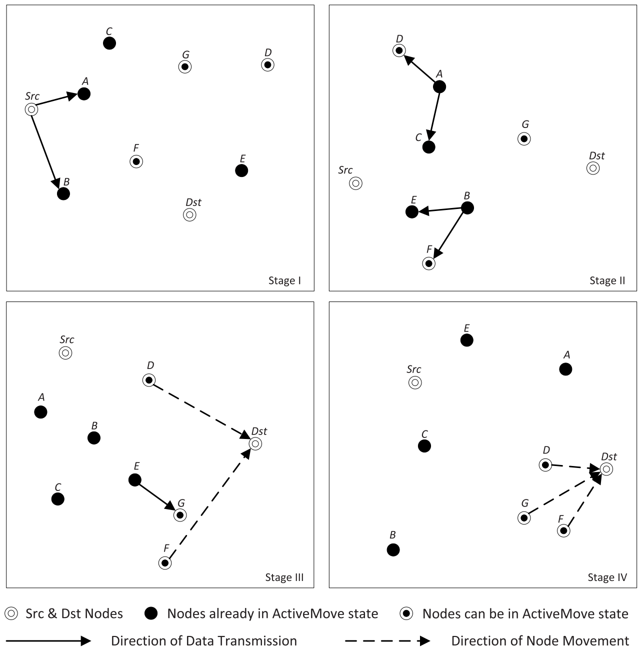


FIGURE 2. Illustration of how nodes gather to the same area.

B. UTILITY FUNCTION DESIGN

In real network environment, due to constraints imposed by certain conditions such as node distribution, motion state, node attributes and available resources etc., the activity range of node is usually restricted and data can not be delivered directly to its target. It can only be forwarded to relaying nodes for further delivery. Hence the selection of relaying nodes becomes an important issue.

1) MODEL OF FREE MOTION DEGREE

Since opportunistic network exploits contact opportunities created by node movement to transmit data, we think it should make full use of the motion characters of node to serve data transmission better. Especially when data is to be forwarded, node mobility should be taken into consideration.

Free motion degree function F_i indicates the capability of free movement of node, depending on node activity range R_i, node centrality H_i and residual energy E_i, which satisfies:

$$\begin{cases} F_i = \dfrac{\alpha E_i R_i}{H_i} + \beta\delta_i \\ \alpha + \beta = 1 \end{cases} \tag{3}$$

α and β represent impact factors respectively, δ denotes disturbance factor. Activity range reflects the distribution of node activity area, which satisfies:

$$R_i = S_{\underset{i}{RAA}} + S_{\underset{i}{RDA}} + S_{\underset{i}{AAA}} = \sum_{w\in W} S_{\underset{i}{w}} - S_{\underset{i}{IAA}} \tag{4}$$

$S_{\underset{i}{RAA}}$, $S_{\underset{i}{RDA}}$, $S_{\underset{i}{AAA}}$ and $S_{\underset{i}{IAA}}$ represent activity range for RAA, RDA, AAA and IAA respectively, W denotes activity range set of all the above areas. The overall distribution of nodes can be consistent by setting different IAA sizes, thus we can get the normalized activity range as:

$$R_{\underset{i}{NRM}} = \frac{\sum_{w\in W} S_{\underset{i}{w}} - S_{\underset{i}{IAA}}}{\sum_{w\in W} S_{\underset{i}{w}}} = 1 - \frac{S_{\underset{i}{IAA}}}{\sum_{w\in W} S_w} \tag{5}$$

where $R_{\underset{i}{NRM}}$ is normalized parameter of activity range, $\sum_{w\in W} S_w$ is a constant which satisfies:

$$\sum_{w\in W} S_w = \bigcup_{i\in T}\left(\sum_{w\in W} S_{\underset{i}{w}}\right) \tag{6}$$

where T denotes node set. It can be seen that the smaller the size of IAA, the bigger the range that node can visit, providing more free motion degree.

Node centrality parameter reflects the status of node during its communication, depending on the connections it built between itself and its immediate upstream nodes and immediate downstream nodes respectively. We define I_i as incoming degree of node i to be the ratio of the number of upstream nodes which forward data directly to node i to the total number of nodes in network. Accordingly, outgoing degree O_i is defined to be the ratio of the number of downstream nodes receiving data directly from node i to the total number of nodes, hence we have:

$$\begin{cases} I_i = \dfrac{\sum N_{i-1}}{\sum_{t\in T} N_t} \\ O_i = \dfrac{\sum N_{i+1}}{\sum_{t\in T} N_t} \end{cases} \tag{7}$$

$i-1$ and $i+1$ denote immediate upstream nodes and immediate downstream nodes respectively, N represents number of nodes. A higher incoming degree means a stronger capability of flow aggregation, which makes it a good traffic hub. Meanwhile, the bigger the outgoing degree, the stronger the communication adaptability, providing more forwarding options for data relaying. Accordingly node centrality index H_i is defined as:

$$\begin{cases} H_i = uI_i + vO_i \\ u + v = 1 \end{cases} \tag{8}$$

where u and v denote weights of incoming and outgoing degrees respectively. The higher the node centrality, the stronger the restrictions imposed on node movement, which depresses the free degree of motion.

Residual energy represents the remained electric quantity that the node has irrespective of the energy type. The normalization of energy is achieved by:

$$E_{\underset{i}{NRM}} = \frac{E_i}{E_{\underset{i}{max}}} = \frac{E_{\underset{i}{init}} - E_{\underset{i}{csm}} + E_{\underset{i}{rec}}}{E_{\underset{i}{max}}} \tag{9}$$

of which $E_{\underset{i}{max}}$, $E_{\underset{i}{init}}$, $E_{\underset{i}{csm}}$ and $E_{\underset{i}{rec}}$ denote maximum energy, initial energy, consumed energy and recharge energy respectively. In general, the energy replenishment is usually cyclical and satisfies:

$$E_{\underset{i}{init}} = E_{\underset{i}{max}} \tag{10}$$

Considering the relevance between energy consumption and data communication [38], [40], the relationship between data transmit-receive and energy consumption is established as:

$$E_{\underset{i}{csm}} = \left(\mu\, T_{\underset{i}{tx}} + \lambda\, T_{\underset{i}{rx}}\right) E_{\underset{i}{max}} \tag{11}$$

$T_{\underset{i}{tx}}$ and $T_{\underset{i}{rx}}$ represent the number of transmitted and received packets separately, μ and λ denote energy consumption factors of transmitting and receiving respectively, thus we can get:

$$E_{\underset{i}{NRM}} = 1 - \left(\mu\, T_{\underset{i}{tx}} + \lambda\, T_{\underset{i}{rx}}\right) \tag{12}$$

Higher residual energy level assures stronger motion capability, providing higher degree of free move. From equation (3) $\sim$ (12) we get:

$$\begin{cases} F_i = \beta\delta_i + \\ \dfrac{\alpha \sum_{t\in T} N_t \left[1 - \left(\mu\, T_{\underset{i}{tx}} + \lambda\, T_{\underset{i}{rx}}\right)\right]\left[1 - \dfrac{S_{\underset{i}{IAA}}}{\bigcup_{i\in T}\left(\sum_{w\in W} S_{\underset{i}{w}}\right)}\right]}{u\sum N_{i-1} + v\sum N_{i+1}} \\ \alpha + \beta = 1 \\ u + v = 1 \end{cases} \tag{13}$$

2) UTILITY FUNCTION CONSTRUCTION

In general people think that the node with prominent central position in network is more likely to be chosen as a relaying node. However, the aggregation of traffics produces a local flow congestion, which counts against the performance of data transmission. Considering the motion characters and

PreRelease Tag	Node ID	Sequence ID	Start Time 1	End Time 1	Position 1	Start Time 2	End Time 2	Position 2	....	End Tag

FIGURE 3. Pre-released message of itinerary.

data forwarding priorities, the utility function $U(m, s, i)$ is constructed as:

$$U(m, s, i) = F_i P_\gamma(m, s, i) \tag{14}$$

Thus we can get:

$$\begin{cases} U(m, s, i) = B_m D_m \max\limits_{j\in\gamma} G_j \times \\ \left\{ \dfrac{\alpha \sum\limits_{t\in T} N_t \left[1-\left(\mu T_{tx_i} + \lambda T_{rx_i}\right)\right]\left[1-\dfrac{S_{IAA_i}}{\bigcup\limits_{i\in T}\left(\sum\limits_{w\in W} S_{w_i}\right)}\right]}{u\sum N_{i-1} + v\sum N_{i+1}} + \beta\delta_i \right\} \\ \alpha + \beta = 1 \\ u + v = 1 \end{cases} \tag{15}$$

The utility function can comprehensively reflect both mobility level and data forwarding priority to characterize multiple attributes of data transmission. Utility Function Index (UFI) is thus defined by removing variables that are directly related to data m as:

$$UFI_{s,i} = \max_{j\in\gamma} G_j \times \left\{ \frac{\alpha \sum\limits_{t\in T} N_t \left[1-\left(\mu T_{tx_i} + \lambda T_{rx_i}\right)\right]\left[1-\dfrac{S_{IAA_i}}{\bigcup\limits_{i\in T}\left(\sum\limits_{w\in W} S_{w_i}\right)}\right]}{u\sum N_{i-1} + v\sum N_{i+1}} + \beta\delta_i \right\} \tag{16}$$

When high priority data is transmitted, instant and effective delivery are of most importance, which is guaranteed by both active move and flooding scheme. For ordinary data transmission, network overhead is considered and node chain priority and node mobility are measured to determine whether or not the data should be forwarded. Generally, a higher node chain priority accompany with a stronger motion ability makes it more suitable for data relaying. When two nodes meet, data is transferred from the one with lower UFI value to the higher one to realize data relaying.

C. ALGORITHM DESIGN AND IMPLEMENTATION

Based on above analysis, Adaptive Motion based Opportunistic Routing (AMOR) algorithm is proposed. With the widely use of GPS devices, the terminal position has become an important information for network applications. The system is deployed with a node position server to manage location information for all nodes. Node pre-releases its itinerary to position server in advance. The format of pre-released message is illustrated in Fig. 3, of which the end time fields are optional. When the distance deviation between its current position and the pre-released itinerary exceeds the predefined threshold, which means a big change occurred for node position, it promptly pushes a realtime position update to the server. The update message is illuminated in Fig. 4. The server updates its position information according to the sequence number of the message. On receipt of a query request, the server replies with the latest position of the node being queried.

Position Update Tag	Node ID	Sequence ID	Current Time	Current Position

FIGURE 4. Location update message.

Details of the protocol are explained as the following steps:

- Each message generated is assigned a unique ID. The list of all the packet IDs in a node's buffer is called Summary Vector.
- When two nodes encounter, they exchange their summary vectors. Data packet that is stored in one node but not in the other is transmitted to the other node if necessary, depending on its data forwarding priority and the position of the destination. The transmission starts until the contact duration ends.
- Once a direct delivery decision is made, the TTL value of the packet is set to 1 so that the packet can only be transmitted to its destination directly without any further forwarding.

The time complexity is $O(|SV| \times n)$, n is the number of nodes in network. The pseudo code for the proposed protocol is presented as follows:

```
Input: node a, node b, ContactDuration
RemoveExpiredPacket(a,b)
ExchangeSummaryVector(a,b)
UpdateNodeState(a,b)
IF ContactDuration > 0 THEN
  IF pkt = GetPacket(a) THEN
    IF NotReceivedBefore(pkt,b) THEN
      IF IsDestination(pkt,b) THEN
        SendPacket(pkt,a)
        ConsumePacket(pkt,b)
      ELSE IF MoveMode(a)==ActiveMove &&
          pkt.target == MoveTarget(a) ||
          MoveMode(b) == ActiveMove THEN
        SendPacket(pkt,a)
        StorePacket(pkt,b)
      ELSE IF DFPEval(pkt) == UrgentFwd THEN
        IF LocateTarget(pkt,b) == IAA THEN
```

```
            SendPacket(pkt,a)
            StorePacket(pkt,b)
        ELSE
            SendPacket(pkt,a)
            SetTTL(pkt,1)
            StorePacket(pkt,b)
            ResetMoveTarget(pkt.target,b)
            ResetMoveMode(ActiveMove,b)
        endIF
    ELSE IF DFPEval(pkt) == PreferFwd THEN
        IF LocateTarget(pkt,b) == RDA THEN
            SendPacket(pkt,a)
            SetTTL(pkt,1)
            StorePacket(pkt,b)
            ResetMoveTarget(pkt.target,b)
            ResetMoveMode(ActiveMove,b)
        ELSE IF LocateTarget(pkt,b) == RAA THEN
            SendPacket(pkt,a)
            SetTTL(pkt,1)
            StorePacket(pkt,b)
        ELSE IF LocateTarget(pkt,b) == IAA THEN
            SendPacket(pkt,a)
            IF UFISatisfied(pkt,b) THEN
                StorePacket(pkt,b)
            endIF
        ELSE
            SendPacket(pkt,a)
            StorePacket(pkt,b)
            ResetMoveTarget(CoordinatedMove
            Target(b),b)
        endIF
    ELSE
        IF LocateTarget(pkt,b) == RAA THEN
            SendPacket(pkt,a)
            SetTTL(pkt,1)
            StorePacket(pkt,b)
        ELSE
            IF UFISatisfied(pkt,b) THEN
                SendPacket(pkt,a)
                StorePacket(pkt,b)
            endIF
        endIF
    endIF
    ContactDuration = ContactDuration-size(pkt)
  endIF
 endIF
endIF
```

III. SIMULATION AND PERFORMANCE EVALUATION

We use ONE (Opportunistic Networking Environment) simulation tool to evaluate the performance of the proposed algorithm against other typical routing protocols. In our daily life, nodes are usually organized in groups and each group has different attributes. Take an industrial park as an example, staff can be grouped into three categories: Senior Executives, Mid-Level Management and Workers, of which senior executives are endowed with the highest priority, the mid-level management are given medium priority and workers, the lowest. The distribution of the industrial park is shown in Fig. 5, which is consisted of residential zone (including worker dorm, management apartment and service flat), living zone (including supermarket, school, kindergarten, hospital, business area and restaurant I, II etc.), production zone (including workshop I∼VII) and office zone (including management service area I, II and executive area). We define respective access areas for different staff categories according to their daily behavior characteristics as shown in Table 2.

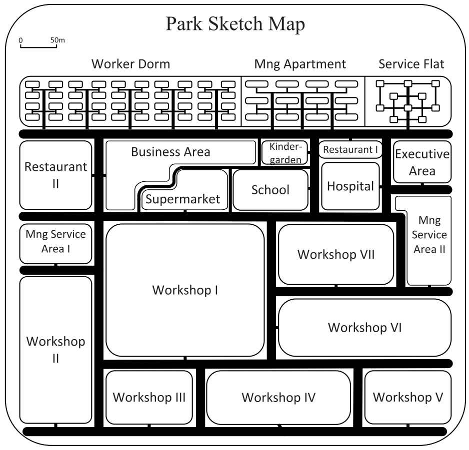


FIGURE 5. Sketch map of industrial park.

All priority parameters are set to three different levels with values of 4, 2 and 1 respectively and the proportions are displayed in percentage as shown in Table 3. Then data forwarding priorities and their corresponding probabilities are calculated accordingly as shown in Table 4. It can be seen that the occurrence probabilities of urgent forwarding, preferential forwarding and normal forwarding is 0.005:0.125:0.87, which is consistent with normal situation. Considering the load balance problem, we increase the weight of outgoing degree and set the parameters accordingly as $u = 0.4$, $v = 0.6$. In the meantime, we neglect the disturbance factors of motion degree with $\alpha = 1$, $\beta = 0$. The normalized parameters of activity range for park staff are calculated based on Table 2 as: $R_{NRM_{SenExc}} = 1$, $R_{NRM_{MidMng}} = 1$, $R_{NRM_{Worker}} = 0.972$. And other parameters are listed in Table 5.

We then choose Direct Transmission (DT), Epidemic Routing, Spray and Wait (S&W) and PRoPHET to compare with the proposed AMOR protocol for performance evaluation.

A. PACKET DELIVERY RATIO

Packet delivery ratio is the ratio of the number of delivered messages to the total number of messages generated. We change the node density and get the consequent packet delivery ratio for each protocol as shown in Fig. 6. It can be

TABLE 2. Illustration of access area for industrial park staff.

Target Area / Staff	RAA	RDA	AAA	IAA
Senior Executives	Restaurant & Service Flat & Executive Area	Living Area & Production Area & Mng Service Area	Mng Apartment & Work Dorm	None
Mid-Level Management	Restaurant & Mng Apartment & Production Area & Mng Service Area	Living Area & Executive Area	Service Flat & Work Dorm	None
Workers	Restaurant & Worker Dorm & Production Area	Living Area & Mng Service Area	Mng Apartment & Executive Area	Service Flat

TABLE 3. Priorities and proportions.

Value / Priority	4	2	1
Node Priority	Senior Executives (5%)	Mid-Level Management (15%)	Workers (80%)
Content Priority	Major Information (10%)	Important Information (30%)	Ordinary Information (60%)
Delay Priority	Critical Delivery (10%)	Preferred Delivery (30%)	Best Effort Delivery (60%)

TABLE 4. DFP ranges and probabilities.

DFP	Value	Probability
Urgent Forwarding	64	0.0005
	32	0.0045
Preferential Forwarding	16	0.0275
	8	0.0975
Normal Forwarding	4	0.24
	2	0.342
	1	0.288

TABLE 5. Experiment parameters.

Parameter	Value
Map Size	600m × 500m
λ	4.5×10^{-6}
μ	5.5×10^{-6}
Message Size	500 KB
Interface Transmission Speed	250 KB/s
Interface Transmission Range	20 m
TTL	6 hrs
Movement Model	Shortest Path Map-Based Movement
Move Speed	0.5-1.5 m/s
Simulation Duration	12 hrs

seen that the connectivity of network can be increased with growing node density to improve the number of delivered packets, while producing more redundancy.

Compared with Epidemic Routing, which adopts full network flooding to provide the lowest delivery ratio, the single copy transmission strategy of DT, the partial network flooding scheme of S&W, and the node selection mechanism of PRoPHET can all effectively reduce the number of packets produced to achieve a higher delivery ratio.

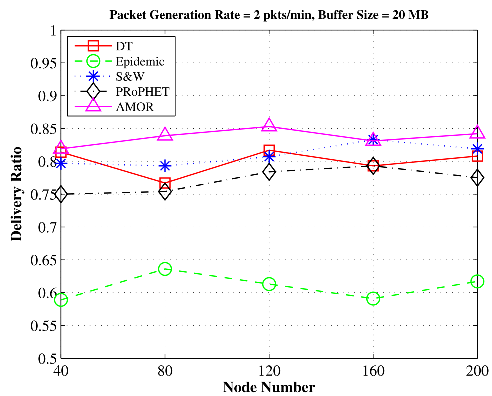


FIGURE 6. Impact of node number on packet delivery ratio.

The motion forwarding mechanism proposed by AMOR guarantees its data delivery. Although its differential replica transfer scheme adopts flooding mode to deliver high priority data, this type of data is relatively small (The proportion of urgent forwarding is only 0.5% in our simulation). For most of other types of data including preferential forwarding data and normal forwarding data, AMOR utilizes conditional forwarding strategy to choose more flexible nodes to participate in data relaying while reducing the number of copies and refraining blindly flooding, which increases the packet delivery ratio.

We then change the network load with a fixed number of nodes. It can be seen from Fig. 7 that the delivery ratio of each protocol is decreased obviously with the increase of load traffic. It is due to the buffer overflow resulting from excessive load to produce lower packet delivery ratio.

B. TRANSMISSION DELAY

Transmission delay is the duration that the message is sent from source node to the target node. Because DT protocol

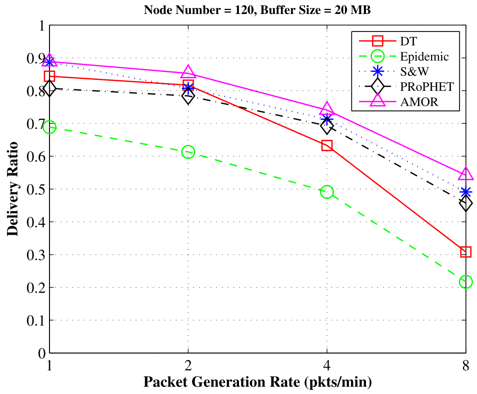


FIGURE 7. Impact of traffic load on packet delivery ratio.

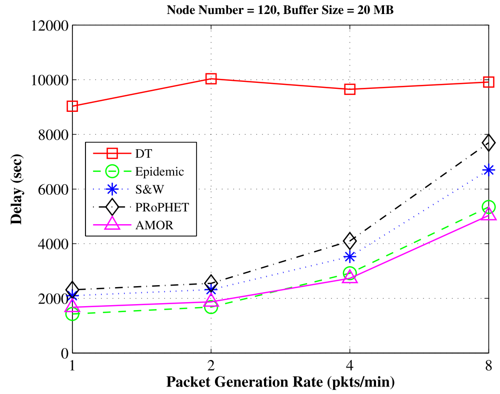


FIGURE 9. Impact of traffic load on packet delay.

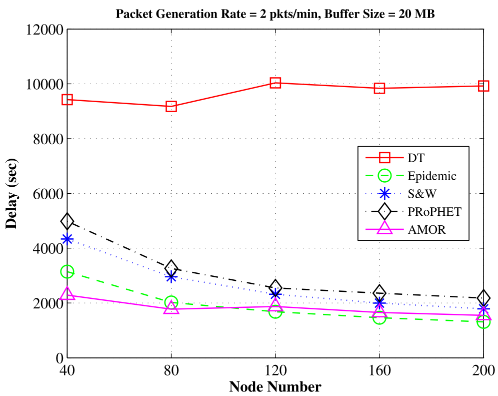


FIGURE 8. Impact of node number on packet delay.

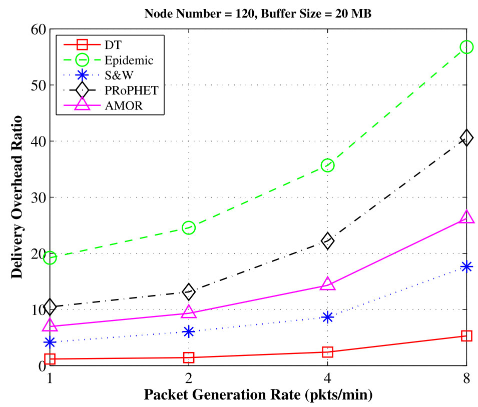


FIGURE 10. Impact of traffic load on delivery overhead ratio.

adopts single copy transmission strategy, node caches data until it meets the target node, its transmission delay depends on the encounter probability between nodes. For other protocols, with the increase of node number, the selection for path is increased too, providing a easier way to find a path with shorter delay as shown in Fig. 8.

The impact of traffic load on packet delay is illuminated in Fig. 9. It can be seen that with the increase of network load, the packet loss rate increases gradually, lengthening the transmission latency. Due to its full network flooding strategy, the Epidemic Routing protocol achieves a shorter delay under lower traffic loads. But with the increase of data traffic, the packet loss rate increases too, leading to a raise of transmission delay. The AMOR protocol makes up for the inadequate coverage of flooding propagation effectively through active movement. At the same time, the proposed identical target data piggyback strategy releases redundant transmission resources and optimizes task scheduling while guaranteeing the efficient delivery of high priority data, which decreases transmission latency further.

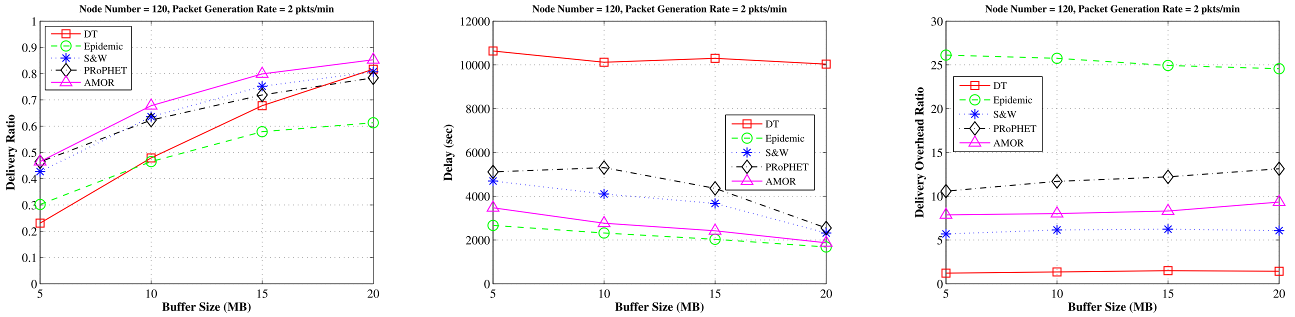
C. DELIVERY OVERHEAD RATIO

Delivery overhead ratio is the ratio of the number of forwarded packets to the number of successfully delivered packets. The higher the delivery overhead ratio, the greater the cost required to implement data transmission, the more the resource is occupied. The impact of network load on delivery overhead ratio is shown in Fig. 10.

Since DT protocol only delivers data to its target node directly which does not require any transmission of signaling, it does not incur additional expense and thus achieves the lowest overhead. Epidemic routing produces redundant packets due to its full network flooding, leading to a higher overhead ratio. AMOR protocol is required to obtain position information of nodes which brings some overhead to the network, however, the proposed identical target data piggyback strategy releases redundant resources to realize re-allocation of transmission resources to alleviate local traffic congestion. And its differential replica transfer scheme also refrains packet redundancy caused by blindly forwarding while guaranteeing delivery for high priority data. Meanwhile, AMOR selects appropriate relaying nodes for data forwarding to reduce its network overhead further.

D. IMPACT OF BUFFER SIZE

As shown in Fig. 11, it is obvious that with the increase of buffer size, the number of dropped packets is decreased, resulting in an increase in delivered packets, which enhances the delivery ratio accordingly.



(a) DR vs. Buffer Size (b) Delay vs. Buffer Size (c) DOR vs. Buffer Size

FIGURE 11. **Impact of buffer size on packet delivery ratio, delay and delivery overhead ratio.**

IV. CONCLUSION

In this paper, we design an opportunistic network routing algorithm based on motion characters of mobile nodes to build a fast and effective communication link by adjusting trajectory of nodes. Based on diverse requirements of different applications, data forwarding priority for each transmission is evaluated to decide the delivery strategy to provide more adaptivity. Considering the transmission efficiency and network overhead, a differential replica transfer mechanism is proposed to deal with data transmissions with different priorities. Moreover, identical target data piggyback strategy is adopted to release redundant resources while alleviating local traffic congestion. A utility function is then introduced based on free motion degree model to optimize selection of relaying nodes. The conducted simulation experiments demonstrate that the proposed AMOR algorithm caters for the requirements of applications and it guarantees the delivery of data while refraining the system overhead to produce lower transmission latency. In future work, we will take security problem into consideration and improve system model further to resist the network destruction incurred by malicious nodes and selfish nodes.

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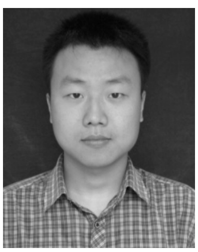

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