Enhanced Shortest Path Routing Algorithm for Named Data Mobile Ad-Hoc Network

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Abstract. Named Data Network (NDN) technology can efficiently mitigate the negative influence due to instable links and dynamic topology on MANET performance. Considering MANET nodes' mobility, this paper enhances NDN's shortest path routing algorithm by storing the interest packets generated by the consumers in the pending interest tables (PITs) of the shortest path's neighboring nodes, aiming at building the backup paths for transmitting back the requested data packets, so as to mitigate the shortest path disruption problem caused by MANET topology dynamicity. This paper designs and implements a simulation platform based on NS3/ndnSIM, and the experimental results indicate that, the enhanced shortest path plus backup (SPPB) algorithm can effectively decrease the average request response delay and improve successful request response ratio.

Keywords: Named data network (NDN) · Mobile ad-hoc network (MANET) · Routing algorithm · Quality of service · Network simulation

1 Introduction

MANET is a peer-to-peer wireless network composed of multiple mobile nodes with topology changing dynamically. Its performance is vulnerable to packet loss and transmission errors. It is required that at least one complete route existing between two communicating nodes, to successfully transmit control and data information. Efficient networking protocol is crucial to guarantee MANET performance. TCP/IP protocol relies on IP address to identify and locate network nodes, as well as to build P2P connections for reliable transmissions. However, considering the mobility feature of MANET nodes, it is impossible to locate network nodes based on IP addresses alone. For the connection-oriented services, IP based MANET has the problems of short connection duration with frequent interruptions. While for the best-effort services, a high packet loss ratio will significantly degrade network performance. Therefore, IP protocol is not suitable for highly dynamic MANETs.

Information Centric Networking (ICN) is one major future networking architecture, and NDN is its most representative technical implementation [1]. NDN adopts the

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receiver driven pattern and can realize asynchronous communications between two network nodes without constructing and maintaining a dedicated connection. In addition, the in-networking caching mechanism employed by NDN enables the network nodes to make full use of the wireless broadcast feature, which can effectively reduce redundant information and can shorten the request response delay. Therefore, NDN are more suitable for the data transmission needs in highly dynamic MANETs. In the following of this paper, NDN based MANET is called NDMANET.

Currently, naming, routing/forwarding, caching, security, and transport are the five major research areas of NDMANET [2]. Among them, routing algorithm is vital to networking performance. NDMANET's flooding and shortest path routing (SPR) algorithms are directly adopted from the fixed NDN networks, and are not optimized for MANET. Considering MANET's frequent link interruptions and topology changes, this paper focuses on enhancing the SPR algorithm for NDMANET. The principle is that, all the neighboring nodes along the shortest path determined by the original SPR algorithm will store the received interest packet in PIT, so as to create backup paths for transmitting the requested data packet, alleviating the shortest path interruption problems caused by frequent topology changes. In this way, the transmission failure probability can be reduced. The major contribution of this work includes:

- Elaborates an innovative shortest path plus backup (SPPB) routing algorithm to enhance the legacy algorithm, without changing NDMANET's protocol architecture;
- Based on the widely used NS3/ndnSIM simulation framework, designs and implements a NDMANET simulator to effectively evaluate the performance of different routing algorithms;
- Based on the derived simulator, comparative simulation experiments for the default flooding routing algorithm, the legacy shortest path routing algorithm and the proposed SPPB routing algorithm are conducted.

The remaining part of this paper goes as follows. Section 2 investigates the state-of-the-art on NDMANET routing algorithms. Section 3 briefly introduces NDMANET, and two legacy routing algorithms. A novel shortest path plus backup routing algorithm for NDMANET is derived in Sect. 4. In Sect. 5, based on NS3/ndnSIM framework, a dedicated simulator is developed for evaluating NDMANET performance, and comprehensive simulation experiments are carried out, and the comparative results are carefully analyzed and discussed. Finally, Sect. 6 concludes the paper and provides the outlook.

2 Related Work

Typically, NDMANET's routing algorithms can be categorized into three types, namely reactive, active and opportunistic classes. **Reactive routing algorithms** do not generate the routes in advance, while only calculate them when it is needed, which can effectively reduce network bandwidth consumption and computing overheads caused by flooding interest packets. Zhang et al. [3] proposed a forwarding strategy based on neighboring nodes perception. Each node maintains the information of its adjacent nodes and their request information. Rehman et al. [4] proposed an on-demand multi-path caching and forwarding strategy based on location awareness to solve the problems of packet conflict, excessive bandwidth consumption, and packet redundancy in NDMANET. Rehman et al. [5] proposed a robust and effective multi-path interest forwarding strategy to reduce NDMANET's unnecessary interest packets broadcasting by using controlled flooding mechanism. Cui et al. [6] elaborates an algorithm to balance network overhead and success rate of content retrieval.

To establish a route to deliver content, **active routing algorithms** require each node to actively broadcast its location information or the content name prefix. In order to achieve mobility robustness in the high speed situation of ICN-MANET, HBFR [7] utilizes completely distributed BF aggregation without cluster heads being in charge of. The CSAR algorithm presented by JianKuang in [8] considers that each content has its special content-scent and can be found by tracing the scent it spreads over the ICN. In [9] presents a lightweight name-based content retrieving algorithm for a multi-hop wireless CCN based on a three-tier strategy that consists of a periodic forwarder information updating, an eligible forwarder selection, and a reliable CCN message broadcasting strategy methods.

Content discovery exists in both active and reactive routing processes. To eliminate the overheads of flooding and the routing failure caused by frequent topology changes, a passive discovery mechanism called **opportunistic routing** was proposed. Yu et al. [10] derived the LER algorithm, which uses the encounters between nodes to broadcast interest packets. Anastasiades et al. [11, 12] proposed an agent-assisted content retrieval scheme, which takes one-hop neighboring nodes as potential agents to retrieve contents. Lu et al. [13] developed STCR, an opportunistic content routing scheme based on social relations. Each node maintains a social relationship table, containing relations of nodes. SACR [14] algorithm uses a group of mobile nodes to distribute random groups periodically, and calculates the centrality of nodes.

To summarize, active routing algorithms perform better for small scale MANETs with relatively stable topology. Opportunistic routing algorithms may lead to considerable transmission delays, and are suitable for applications insensitive of latency. Reactive routing algorithms are deficient in highly dynamic MANET scenarios. This paper focuses on NDMANET's shortest path routing algorithms. As a typical example, listen first broadcast later (LFBL) [15, 16] algorithm introduces the distance table (DT), which records the distance from current node to consumer and to producer, so as to determine the appropriate forwarder. Similarly, CHANET in [17, 18] introduced the content source tables CPT and PRT in each node, which only forwards the packet when it is closer to the consumer than the preferred provider. CCVN [19, 20] has enhanced CHANET for VANET scenarios. However, the aforementioned algorithms are not improved for highly dynamic MANETs.

3 NDMANET and Its Routing Algorithms

3.1 IP Based MANET

At present, the network layer of MANET usually adopts Internet protocol (IP), which has already achieved great success in fixed networks while may not be an efficient L3 protocol for highly dynamic MANETs. The reasons lie in the following three aspects:

- IP based MANET is host-centric network (HCN). IP address is not only a node identifier, but also a node locator, used to indicate its geographic position. Once a MANET node moves out of the network boundary, it cannot be located, and its path established with other nodes on IP will also disconnect;
- To keep the binding relationship with others, networking nodes of highly dynamic MANET update their location information to each other in real time, and this will generate a large amount of control information and may increase bandwidth consumption, thus to further degrade network performance;
- IP based MANET uses sender driven mode, which may not effectively utilize all the intermediate nodes to forward information, thus cannot build the optimal routing path on the basis of global information.

3.2 NDN Based MANET

NDN based MANET (NDMANET) can much better support node mobility and dynamic topology. The major reasons are:

- NDMANET belongs to ICN, which utilizes the content name to identify each packet. The networking nodes can produce and consume content based on its name. The content position is not required, neither the node address;
- The receiver driven mode based NDMANET needs not to establish connections between communicating nodes, so it will not be influenced by the frequent interruptions of wireless links and dynamic changes of network topology;
- NDMANET separates content from location, and reuses the historical received packets stored in the intermediate nodes through network caching mechanism, thus can further accelerating transmission rate and reducing bandwidth consumption.

Compared with IP protocol, NDN technology can provide better networking performance for applications and users in highly dynamic MANET scenarios.

3.3 NDMANET Routing Algorithms

Currently, most NDMANET routing algorithms are originated from NDN's practice in fixed networks, and are not optimized for MANET. They are:

- **Flood Routing Algorithm.** A consumer node broadcasts an interest packet, and all its neighboring nodes can receive it. The receivers will forward the packet again via broadcasting until the interest packet encounters a node storing the requested data packet. Then, this node will broadcast the data packet and transmit it back to the consumer nodes along the reverse propagation path of the interest packet;
- **LFBL Algorithm.** A consumer broadcast an interest packet. Each intermediate node maintains its distance to consumer as *CD*. Producer receives the interest packet and can obtain its distance to consumer, then inserts the distance value into the requested data packet. When the intermediate nodes receive the data packet, it extracts the distance value *PD* to producer, and the shortest distance *MD* between producer and consumer. When an intermediate node receives a packet, it will evaluate the inequality:

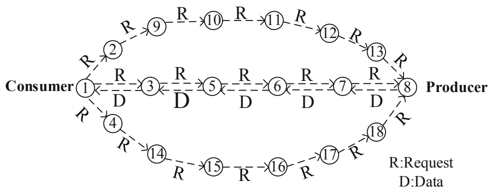

Fig. 1. Schematic of the shortest path lookup and build process

$$CD + PD \leq MD.$$

If the inequality is true, the packet will be forwarded according to the corresponding record in PIT table. Otherwise, the packet will not be forwarded.

4 Innovative Shortest Path Plus Backup Routing Algorithm

4.1 Design Principle

This paper elaborates a shortest path plus backup (SPPB) routing algorithm which enhances the legacy SPR algorithm. The basic idea is that, all the neighboring nodes along the shortest path determined by the original SPR algorithm will store the received interest packet in PIT, so as to create redundant routes for sending back the requested data packet, alleviating the shortest path interruption problems caused by frequent topology changes in highly dynamic MANET scenarios. Two major steps are included.

Identify the Shortest Transmission Path. First, a consumer in NDMANET broadcasts an interest packet for path seeking. When the producer receives the packet, the hop count of this packet is used as the distance indicator of this path. Then, the producer generates the requested data packet and sends it back to the consumer. Figure 1 demonstrates the above procedure. The consumer ① floods the first interest packet to the entire network. The producer ⑧ returns the requested data packet. When an intermediate node receives one data packet, it will record the hop count to local repository. For example, the number of intermediate nodes between ⑪ and the producer ⑧ is 2. When the data packet is sent from the producer ⑧ to the consumer ①, the consumer can finally obtain three different distance hop values, which are 5, 7, and 7, respectively. The consumer can then utilize the path with the minimum hop count as the shortest path. The hop information of the above three paths are shown in Table 1. At a certain moment, the hop counts summation of the interest packet and the data packet is a fixed value on the same data transmission path. The smaller the value, the shorter the distance between the consumer and the producer.

Constructing Backup Paths Using Shortest Path's Neighboring Nodes. As is shown in Fig. 2 (a), nodes ② and ④ as the neighboring nodes of the consumer ① are not on the shortest path. The SPPB algorithm can set the two nodes as backup intermediate nodes of node ③. Similarly, node ⑪ is selected as the backup node of node ⑦. In Fig. 2 (b), it is assumed that, node ③ moves outside the communication range of node ⑤, and node ⑦ also leaves node ⑧. While nodes ② and ⑪ can be used to build a new path

Table 1. Hop counts of interest packet and data packet stored in a node

Node	1	2	3	4	5	6	7	8	9
Data hop	5	6	4	6	3	2	1	0	5
Interest hop	0	1	1	1	2	3	4	5	2
Node	10	11	12	13	14	15	16	17	18
Data hop	4	3	2	1	5	4	3	2	1
Interest hop	3	4	5	6	2	3	4	5	6

between the consumer and the producer. Therefore, this approach can avoid data packet loss caused by routing interruption and retransmissions of interest packets.

4.2 Implementation Details

The implementation of the proposed SPPB routing algorithm includes two parts.

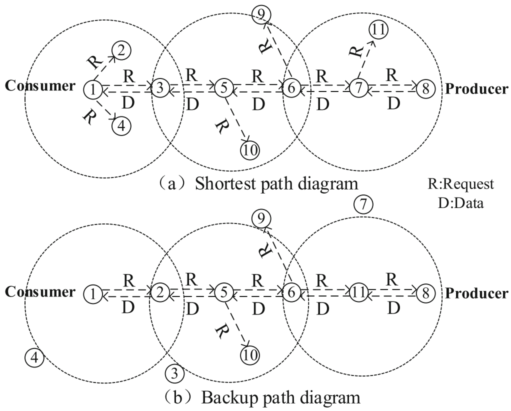

Fig. 2. Schematic of backup node selection and path construction

Interest Packet Processing Flow

- **Current node is a consumer.** When the consumer node generates the first interest packet, the distance hop information carried by the interest packet is set to 0, and the interest packet needs to be flooded to the entire network to dynamically create a shortest routing path between the consumer and the producer. After that, when the intermediate node in the network receives the subsequent interest packets sent by the consumer, it will forward it according to the generated shortest routing path. Besides, when a consumer sends an interest packet and does not receive the requested data packet within a certain period of time, the consumer can consider that the shortest routing path generated has expired, and the consumer will flood an interest packet again to rebuild another shortest route.

Table 2. Interest packet process flow

```
Interest packet processing flow
if current node is consumer then
    set interestHC 0
    if sending interest packet for the first time or data timeout then
        broadcast interest
    else
        set buildSP flag 0
else
    record interestHC
    interest.interestHC=interest.interestHC+1
    if buildSP==0 then
        if interestHC+dataHC≤expectedHC then
            forward interest
        else
            insert interest into PIT
    else if ds.nonce!=interest.nonce then
        forward interest
        record the nonce of interest
```

- **Current node is an intermediate node.** When an intermediate node receives an interest packet, it first records the hop count of the packet (*interestHC*). If the packet is a broadcast packet (if the *buildSP* field in this packet is 1, the packet is a broadcast packet, this field is used to identify whether it is necessary to rebuild the shortest path) and the current node has not previously forwarded the packet, then it forwards the packet. If the packet is not a broadcast packet, it will evaluate the inequality

$$interestHC + dataHC \leq expectedHC$$

where *dataHC* is the hop count of the data packet and *expectedHC* is the expected hop count of the producer to the consumer. If it is true, the interest packet is forwarded; otherwise, the packet is inserted into the PIT table of the node, and the intermediate node becomes a backup node. The pseudo code is shown in Table 2.

Data Packet Processing Flow

- **Current node is a producer.** The producer node records the number of packets sent so far as *Seq*. If the producer receives a broadcasted interest packet, its hop count information will be used as expected distance between the consumer and the producer. The producer sets the hop value of the data packet to 0, and the flag *buildSP* the same as the flag of the interest packet to ensure that subsequent processing can identify the broadcast packet. At the same time, *Seq* is stored in the current data packet to ensure that the record in the intermediate node is only updated by the newly generated data packet.

- **Current node is an intermediate node.** The intermediate node receives a data packet. If the data packet is not broadcasted or the *Seq* of the Data packet is smaller than the *Seq* in local record. The data packet is forwarded directly; otherwise, the *expectedHC* and *Seq* of the data packet need to be recorded. If the *Seq* of the data packet is not equal to the *Seq* recorded by the node or the *dataHC* recorded locally is greater than the *dataHC* of the data packet, the *dataHC* of the data packet is re-recorded in the local record. The pseudo code is given in Table 3.

Table 3. Data packet processing flow

```
Data packet processing flow
if current node is producer then
    data.dataHC=0
    if interest.buildSP==1 then
        data.expectedHC=interestHC-1
    record sequence number of data
    sequence number of data increase 1
    data.buildSP=interest.buildSP
else if data.buildSP==1 and newer then
    if recorded dataHC > data.dataHC then
        record dataHC
    if recorded sequence number of data ≠ data.seq then
        record dataHC
    record expectedHC
    record sequence number of data
    data.dataHC increase 1
if corresponding entry in PIT then
    forward data
```

5 Performance Evaluation

Computer simulation approach is adopted to evaluate the performance of the proposed SPPB algorithm. The performance metrics include: *network bandwidth consumption* (NBC), *average request response delay* (ARRD) and *successful request ratio* (SRR):

- **Network Bandwidth Consumption.** It refers to the amount of content sent or forwarded by all the nodes in NDMANET, during the simulation period, including all the interest and data packets;
- **Average Request Response Delay.** It is defined as the average time delay from the consumer's sending of an interest packet to the final reception of the requested data packet during the simulation period. Assuming that the number of successful packet requests is N and the delay of the i-th packet request is $delay_i$, the ARRD is:

$$ARRD = \frac{\sum_{1}^{N} delay_i}{N}$$

- **Successful Request Ratio.** It is the ratio of the number of data packets received to the number of interest packets sent by the consumer during the simulation period, which indicates that, to which extent, the network can satisfy the customer requests:

$$SRR = \frac{DataCount_{received}}{InterestCount_{sent}}$$

5.1 Developing Simulation Platform

A software simulation platform based on NS3 and ndnSIM is developed. The detailed configurations of the underlying hardware and software are shown in Table 4.

Table 4. Hardware and software configurations of the simulation platform

	Hardware configuration
CPU	AMD Ryzen 7 1700X
RAM	64 GB DDR4 2400MHz
Disk	500 GB SSD
	Software configuration
Operating system	Ubuntu 16.04
NS3 version	3.25
ndnSIM version	2.6

5.2 Simulation Assumptions and Settings

Medially to highly dynamic MANET scenarios are considered and NDMANET nodes can move randomly at a certain speed. In order to make the experimental results comparable, the same random number seed and node mobility models are used in the simulation experiments for three different routing algorithms. The parameter settings for the simulation experiments are summarized in Table 5.

5.3 Simulation Results

First, the experimental results of *network bandwidth consumption* are shown in Fig. 3. The default flood routing algorithm broadcasts interest packets and data packets, while the SPPB and LFBL algorithms can suppress the broadcasts. Compared with the LFBL algorithm, the proposed SPPB algorithm constructs a backup path besides shortest path. Nodes on this backup path may broadcast data packets, which causes the SPPB algorithm to consume slightly more bandwidth than the LFBL algorithm.

Table 5. Scenario parameter settings

Parameter	Value
Protocol	802.11a
Max transfer rate	24 Mbps
Communication radius of each node	75 m
Size of scenario	600 m * 600 m
Amount of node	60–140 (step value of 20)
Speed of node	10 m/s
The frequency of sending Interest packet	10 Interest/s
Simulation time	300 s

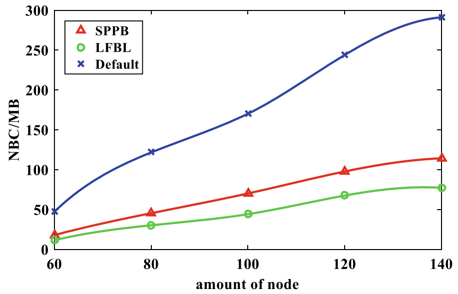

Fig. 3. The experimental results of network bandwidth consumption

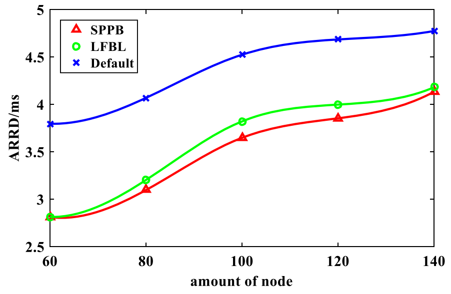

Fig. 4. The experimental results of average request response delay

Secondly, the results of the *average request response delay* are shown in Fig. 4. The default flooding algorithm employs more intermediate nodes for transmitting interest packets and data packets, so the average request response delay is the largest. In the LFBL algorithm, Data packets are transmitted back along a predetermined shortest path, which can effectively reduce the latency. The derived SPPB algorithm considers the network topology dynamicity and provides a backup path option for packet transmitted. Therefore, it can further reduce the request response delay.

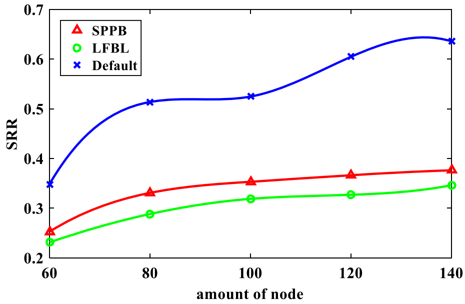

Fig. 5. The experimental results of successful request ratio

Finally, Fig. 5 illustrates the simulation results of the *successful request ratio*. The default flooding algorithm broadcast the packets, so it can lead to the highest successful request ratio. The cost is the largest network bandwidth consumption. The elaborated SPPB algorithm has a higher successful request ratio than the LFBL algorithm. The reason is that the SPPB algorithm builds the backup paths besides the shortest path, which reduces the failure probability of data packet transmitted, thus the successful request ratio gets a certain degree of promotion.

6 Conclusions

NDN technology can reduce negative influence on MANET performance due to unreliable links and dynamic changed topologies. This paper innovatively elaborates a shortest path plus backup (SPPB) routing algorithm to improve NDN's legacy shortest path routing algorithm. The proposed algorithm stores the interest packets generated by the consumer in PITs of the shortest path's neighboring nodes, aiming at building the backup path for transmitting back the requested data packets, so as to mitigate the shortest path disruption problem caused by MANET topology dynamicity, and to lower data packet drop probability. This paper also develops a simulation platform based on NS3/ndnSIM, and the experimental results indicate that the enhanced algorithm consumes limited bandwidth, with further decreasing the average request response delay and improves the request response ratio.

The topology change of MANET also affects the interest packets' transmissions by the shortest path routing algorithm. Therefore, as the next step of this work, further improving the routing performance for the interest packets is planned.

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