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# MANET for Disaster Relief based on NDN

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***Abstract*—During disaster relief situation, there is an acute need for reliable/efficient communication and content distribution, which can be supported by Mobile Ad hoc Networks (MANET) and Delay Tolerant Networks (DTN). Traditional IP protocol performs inefficiently in MANET, while Named Data Networking (NDN) can be more beneficial because of many inbuilt features. In this paper, we propose a solution to adopt NDN for communication in the specific context of disaster relief. Firstly, we propose a proactive routing protocol which is also reactive-routing-enabled. Every node broadcasts their existence to neighbors and synchronizes the Network Information Base in order to update its own FIB. A universal entry set in FIB can be used to probe potential paths. It also remains multiple next-hops for every prefix in FIB in order to support multipath forwarding. Secondly, by duplicating or splitting the queue of Interests at a node, it's able to utilize multipath so as to improve transmission reliability or efficiency. For the convenience of future work, our experiments are carried out in a real platform consisting of some smart cars equipped with Raspberry Pi. Evaluation results show our solution is able to build a communication network by nodes themselves, and supports multipath forwarding with high reliability/efficiency in a disaster relief scenario.**

***Keywords*—*MANET, Named Data Networking, Disaster Relief, Routing, Forwarding***

## I. INTRODUCTION

After a disaster, many technological devices like unmanned aerials vehicles and automatic mobile devices will be applied to disaster relief, and it's necessary to retrieve information from them or convey commands to them timely. Meanwhile, it's important to distribute rescue information such as damage extent, weather prediction, rescue progress etc. to victims as soon as possible. The majority of above communication can be easily achieved with reliable underlying infrastructure, which however, is often partially or totally destroyed during a disaster. What's more, victims' remote friends urgently call to stricken areas for safety confirmation, which leads to high congestion of network infrastructure even if it was unaffected by natural disaster. Since the lack of infrastructure, it's more appropriate to build MANET for communication after a disaster.

MANET is a combination of self-configured, resource-constrained mobile devices that can directly communicate with each other using a short transmission range [1]. MANET features with frequent topological changes and intermittent connection [2]. Such features bring huge challenges when we use MANET to transmit data. Though having achieved huge success in wired Internet, traditional TCP/IP architecture is inappropriate and performs inefficiently in MANET due to the following reasons:

- Each node should be assigned an IP address firstly. IP address stands for a node's identifier as well as topological location. Although the way of Mobile IP can provide support for node movement, it significantly impairs communication efficiency. What's more, IP address management requires infrastructure support such as DHCP server, which is absence in MANET.
- At IP routing plane, IP routes exchange routing information and select a single best path with lowest cost to the given destination IP address in order to construct routing table. Packets will be transmitted strictly alone the alive end-to-end routing path according to routing table. Since frequent node movement, the links on the 'best path' with lowest maybe fail. Or worse, it usually takes a long time for IP routing protocols to converge.
- Generally, for a specified IP address, there is at most one outgoing interface in routing table, i.e., forwarding plane is coupled to routing plane in TCP/IP network. That's why we call it dump forwarding, smart routing [3]. It's obviously a fragile method for network once there are link failures. Besides, packets on wireless channels are broadcast in nature and could be received by neighbors in sender's transmission range. Nevertheless, since there is at most one routing path to a specific destination, MANET can't utilize multiple paths to delivery packets in parallel.

The basic solution to transmission failure is retransmission, which however can be useless in MANET if routing doesn't update path timely. All above reflect inefficiency of IP-routing-based approach in MANET due to IP address management, ill-suited routing protocol and failure to support multipath forwarding.

The need of frequent distribution of information after a disaster hints us to build a distribution network. With simple and robust communication model, NDN [4] is especially appealing for deployment in MANET. Communication in NDN relays on two packet types, Interest and Data. As for command conveyance, commander can emit an Interest carrying commands. After receiving a command Interest, the device will execute the command, meanwhile, return a Data simply carrying ACK. Alubady et al. [5] compare the performance of NDN-based and IP-based MANETs. The result shows that NDN-based MANET are considered as a good candidate for emerging recovery application and natural disaster scenarios.

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In spite of fruitful advantages, communication using NDN-based MANET is still challenging due to frequent topological changes and intermittent connection. Routing and forwarding are two major research directions, where most approaches are effective but need the assistance of additional devices such as GPS, which are usually absent or inconvenient to use in our disaster relief scenario. In this paper, we adopt some basic approaches and propose a routing protocol and a multipath forwarding strategy for NDN-based MANET. The main contributions of this paper are as follows:

- We propose a proactive routing protocol, which is also reactive-routing-enabled. Every node broadcasts their existence to neighbors and synchronizes the Network Information Base (NIB) in order to update its own FIB. A universal entry set in FIB can be used to probe potential paths. It also remains multiple next-hops for every prefix in FIB in order to support multipath forwarding.
- Our proposal implements multipath forwarding by duplicating or splitting the queue of Interests at a node, which significantly improves service reliability and network flexibility.
- To evaluate performance, we develop a real platform consisting of smart cars equipped with Raspberry Pi.

The remainder of this paper is structured as follows. Section II provides an overview of NDN and points out the problems of current routing and forwarding schemes for NDN-based MANET. Section III presents our proposal. We present the evaluation results in Section IV and conclude the paper in Section V.

## II. RELATED WORK

In this section, we briefly introduce NDN and current advances of routing and forwarding mechanism of NDN-based MANET.

### A. NDN Overview

In NDN, Interest carries the name of the requested content (e.g. /USTC/LFN/video/2018). Data carries the content that corresponding Interest requests. Each NDN node is equipped with three main data structures: Content Store (CS), Pending Interest Table (PIT), and Forwarding Information Base (FIB). CS can cache the data packets passing by. Information in PIT acts like “bread crumbs” to help Data Packets come back to the consumer. FIB is generated by routing protocol and used for routing Interests. In order to retrieve content, a consumer injects an Interest in the network. Arriving Interest packets are forwarded using name-based forwarding by looking up the data name in the locally maintained FIB when there are no corresponding entry in CS and no pending Interest packets with the same name in PIT. When a Data coming back, an NDN router matches Data’s name in PIT and forwards the Data to all the faces recorded in the corresponding entry, which will be removed after forwarding. This processing is similar to find the bread crumbs left by Interest. Before Data leaving, the route will decide whether to cache it based on caching strategy.

### B. Routing and Forwarding

In NDN, a routing protocol is used to populate FIB, which provides sufficient potential to enhance content dissemination at the forwarding plane. There are a lot of routing research activities for NDN-based wireless ad-hoc network. From the content discovery, it can be divided into reactive and proactive routing [6].

In fact, most reactive routing protocols omit FIB and on demand or controlled flood Interests. As a result, they merge the process of routing and forwarding.

LFBL [7] is a reactive routing protocol without knowledge of neighbors, routes or next hops. LFBL controls the forwarding at every node based on its distance to the content provider. There is a Distance Table (DT) in every node. DT stores the distance to other nodes and will be updated according to the distance information of arriving packets. As shown in Fig. 1, after receiving a packet from green sender, by accessing the distance recorded in srcDist/dstDist and DT, every node within the signal range of the sender will know whether it is an eligible forwarder or not. In Fig. 1, blue nodes are eligible forwarders due to closer distance to destination than sender’s. Different eligible forwarders need to wait different listen periods to forward packets.

Since LFBL is not initially designed for NDN, LFBL doesn’t employ FIB, CS and PIT. Albeit novel design and compatibility with NDN [2], present LFBL fails to utilize the advantages of NDN. What’s more, a key to LFBL is how to get distance. The authors in [7] introduce two typical distance metrics: hop count and signal strength. However, hop count is hard to know previously without message exchange, and signal strength is undetectable when two nodes are distant enough.

Like LFBL, most reactive routing protocols such as CHANET [8], BREB [9] , V-NDN [10] are distance aware. However, to get distance is not always easy especially in a disaster relief scenario. In LFBL, nodes update their DT with the help of overhearing/passing packets, which will disable in a sparse network featured with little packet transmission.

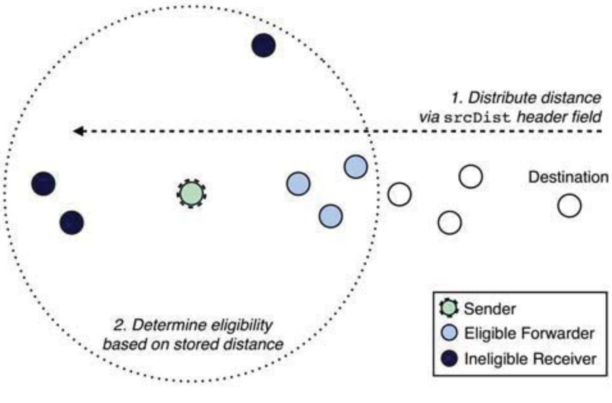


Fig. 1. The eligible forwarders of LFBL[7]

V-NDN’s vehicles are equipped with GPS device, therefore, it’s easy to get geographical location and calculate distance. V-NDN also omits the FIB. To get content, a node will broadcast an Interest. Then every receiver computes its distance to the sender, meanwhile, starts a random *Forwarding Timer* based on distance: the further the distance, the shorter the wait. V-NDN is not appropriate for our scenario since not all rescue devices are provided similar locators. In additional, to select a farthest forwarder, V-NDN introduces an inevitable and unnecessary delay for transmission. Finally, a farthest forwarder doesn't always mean an optimal one, since the farthest one can be selected as next-hop simultaneously by many senders, which lead to congestion in this node.

Proactive scheme requires a routing table to assist forwarding. It can achieve significance performance in the small-scale and relatively stable ad-hoc scenarios. In NDN prototype, node is equipped with a FIB. Can we adopt proactive scheme basically for routing in our scenario?

In [11], Oh et al. proposed MANET CCN, which uses the Content Centric Networking in emergency situation MANET. A node employs basic flooding to send Interest to its neighbors and the gateway of the domain. A receiver looks up the data name in the Meta-Data Registry (a structure similar to FIB) when there is no corresponding entry in CS and no pending Interest packets with the same name in Interest Table. A gateway node floods its meta-data list to neighbors periodically and updates the Meta-Data Registry after getting neighbors' lists. Since the number of gateway nodes is small, MANET CCN won't cost too much network resource.

BFR [12] is designed for urban vehicular ad-hoc network and adopts a Bloom Filter Routing (BFR) to advertise the popular prefixes. With a self-organized geographical hierarchy, BFR can reduce the content discovery cost between clusters. Hierarchical Bloom-Filter Routing (HBFR) [13] is another proactive content discovery scheme which improves BFR. There is no cluster head in each partition to supervise bloom filter aggregation and the aggregation is distributed, which makes HBFR more robust and support highly mobility.

## III. ARCHITECTURE DESCRIPTION

This section gives a description of our proposed routing and multipath forwarding scheme for NDN-based MANET in the specific context of disaster relief.

### A. Motivation and Overview

As discussed in Section II, most reactive routing protocols are distance aware and need a geographical locator or distance metrics, which are lack or invalid in our scenario. What's more, unnecessary delay will be introduced and the selected next-hop is not always the optimal one. As lack of FIB, every time to retrieve a content requires looking for a path by flooding Interest again, which is obviously inefficient. Although some research [7] [14] adopts additional data structures to save distance information, it still needs to update these information by exchanging information periodically. Since in our scenario the network is small-scale and relatively stable, we proposed a proactive routing which is also reactive-routing-enabled.

The basic function of a state link protocol is to discover the neighbors and propagate the topology. To perform distributed collaborative tasks in a MANET environment, it's necessary and beneficial for a node to discover its neighbors in time and construct the topology of the entire network with received information. Unlike traditional IP networks, NDN can use Interest and Data packets to perceive neighbors and propagate routing information.

By periodically broadcasting own identifier, near nodes are able to discover this node. After discovering neighbors, each node synchronizes its NIB by exchanging *sync* Interest and *sync* Data packets. NIB stores the information of each node's neighbors and cached content. Through the NIB, each node can create the topology of the entire network, and obtains multiple paths to the destination. Since FIB remains multiple next-hops for every prefix, we also give a multipath forwarding strategy.

### B. Neighbors discovery

To find neighbors, we subtly identify each node with a custom static IP address. Note that static IP address is only an identifier of nodes, and MAC address or other identifier is also permitted. Each node periodically broadcasts an empty *hello* Interest to the network. The name of the Interest composed of its own IP address identifier, in addition to prefix required by broadcast, e.g. /ndn/broadcast/Interest/192.168.13.1. Fig. 2 shows node B discovering node A. Node B within the broadcast range of A receives the Interest of A, and knows that is a *hello* Interest through the broadcast prefix. Subsequently, B extracts the IP address in the name and creates a forwarding face for node A on its own forwarding plane. If A has not sent Interests for a long time, the corresponding face state of A is set to *OFF*, and it is set to *ON* when node A is reactivated.

By repeating above process, a node can perceive its active neighbors. We highlight there is no need for a receiver to reply *hello* Interests, meanwhile *hello* Interests won't incur too much network burden since they carry nothing but name and the number of nodes is limited in our scenario.

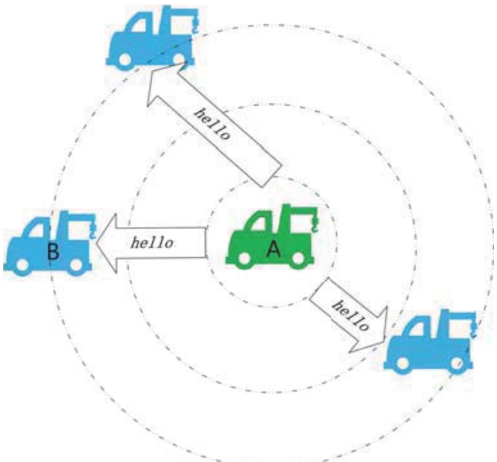


Fig. 2. neighbors discovery

### C. Routing

Considering the objective to perform distributed collaborative tasks for disaster relief, our idea is to synchronize the NIB of each node so as to provide global topology and content information of nodes. According to NIB, nodes can obtain multiple available next-hops for each prefix in FIB by following simple extension of Dijkstra's algorithm. There is no doubt convergence will cost some time, however, NDN routing does not need to converge fast following NIB changes, which can be handled by adaptive forwarding more promptly [15].

After each node discovers its own neighbors, it creates forwarding faces for each neighbor. Through these faces, each node can exchange hash values of the NIB with neighbors by *sync* Interest and *sync* data packets. As shown in Fig. 3, when new content or new node information is added to the NIB of Node A, it will calculate a new hash value and increase the hash's sequence number by 1. Node A subsequently sends each neighbor a *sync* Interest with new hash value. After B receives the *sync* Interest and the new hash value, it compares the new hash value with its own hash value. When two hash values are not equal, B sends an Interest to request missing information. A responds with the information requested in a *sync* Data packet. B then inserts the new information into its NIB. When an old content is deleted or a node fails, similar procedure will be executed. Thus, through NIB, nodes can build the topology of the entire network and update FIB.

Note that though most wireless nodes are equipped with only one wireless adapter thus only one physical wireless interface, it is available for a node to set multiple virtual wireless interfaces so as to connect with its neighbors. In wireless environment, the transmission of messages is in broadcast mode physically, i.e., every node within the signal range of the sender can hear the messages. However, according to NDN Forwarding Daemon (NFD), a core component of the NDN platform, only the arriving Interest/Data specified by the sender can be admitted by the receiver. Hence in NFD, broadcast is defined as forwarding every Interest to all upstream indicated by the FIB entry. We adopt this definition of broadcast for the following sections.

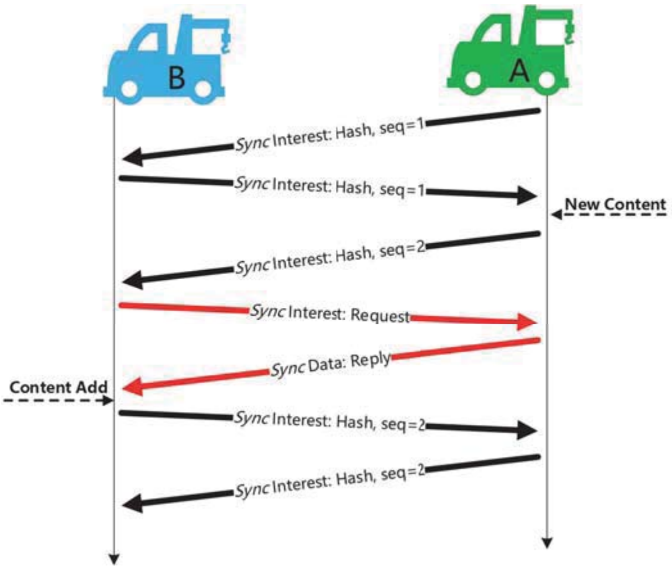


Fig. 3. Synchronization between two nodes

Since NDN's design supports multipath forwarding, there are one or more available next-hops for each prefix in FIB. When a node decides to forward an Interest, it looks up the Interest name in the FIB using longest prefix match. If a matching FIB entry is found, we will propose a forwarding strategy in the next subsection. Here we discuss the situation when matching FIB is not found.

For original NDN, it will discard the Interest once no next-hop found in FIB. While the absence of matching entry may result from unfinished convergence, we insert a universal entry in the last of FIB, and its next-hops are all the neighbors, as shown in Fig. 4. Therefore, any Interest failed to match in FIB previously now will be broadcast to every neighbor, which is essentially a reactive scheme. And when the corresponding Data back, it's beneficial for the node to add a new entry of the request content in FIB, which also speeds up the convergence.

| Node # | |
|---|---|
| *prefix* | *Face ID* |
| prefix 1 | 1,4 |
| prefix 2 | 3 |
| … | … |
| / | 1,2,3,… |

Fig. 4. Adding an universal entry in FIB

The computational complexity of our routing scheme is largely determined by the algorithm to get next-hops. At a specific time slot, if using simple extension of Dijkstra's algorithm, N nodes can get multiple next-hops for K prefixes in O($KN^2$) time complexity. What's more, the maximum number of next-hops per prefix can be specified, and thus we can control the FIB size and the maintenance overhead for FIB at a reasonable level. Every node needs to send periodic *hello* Interests, which is inevitable but somewhat duplicate, so we want to dynamically adjust the transmission interval of *hello* Interests in future work.

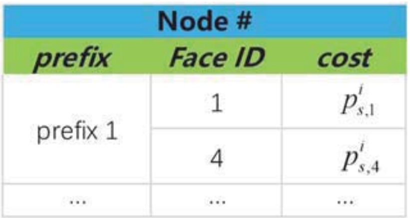
### *D. Multipath Forwarding*

As described in III.C, when a node checks its FIB and finds no or only one next-hop for the arriving Interest, the node will broadcast that Interest to all its neighbors, or transmit the Interest via that exclusive interface, respectively. Here we discuss the situation when there are multiple next-hops for the Interest. A content can be cached in more than one nodes in NDN, which contributes to more than one path available to be followed to retrieve the same content [16]. Consequently, it's important to decide which face(s) to forward the Interest towards the appropriate content containers.

Essentially, the two most rudimentary advantages of multipath forwarding are high reliability and great efficiency. Since some transmission requires high reliability while some requires great efficiency. We design different forwarding strategies to meet these two different objectives.

*1) High reliability:* Some applications need to retrieve data reliably without packet loss. To meet this requirement, we simply utilize multipath feature by broadcasting an Interest to all available interfaces. Though costing too much network resource, it highly meets the requirement and is meaningful in a disaster relief scenario. When the selected multiple paths are disjointed, obviously, the delay to retrieve data in this forwarding strategy is less than a single path forwarding strategy.

*2) High efficiency:* During disaster relief, commander may want to request a surveillance video from a remote mobile car. Since in NDN the maximum size of a Data is 4KB and the request mode is one Interest getting one Data, a requester injects successive Interests to the network. And there will be a long queue of Interests waiting in the buffer of a router. We extent our previous work in [17] to solve this problem. In NFD, every face is bind with a cost value, which can be modified with time. An Interest passing interface will produce a cost. Our idea is to split the queue of Interests and guide them to different interfaces and make the total cost as small as possible, meanwhile, update the cost value of every interface timely.



| Node # | | |
|---|---|---|
| **prefix** | **Face ID** | **cost** |
| prefix 1 | 1 | $p^i_{s,1}$ |
| | 4 | $p^i_{s,4}$ |
| … | … | … |

Fig. 5. Adding cost in FIB

For a given content $s$, we assume node $i$ has a face set $J = \{1, \dots, n\}$, and define $p^i_{s,j}(t)$ as the interface $j$ 's cost of node $i$ at time $t$, as shown in Fig. 5. The physical meaning of an interface's cost can be viewed as the number of Interests congested in the link connected to this interface. According to [17], the cost can be deduced from round-trip time $RTT^i_{s,j}(t)$ :

$$p^i_{s,j}(t+1) = \beta(RTT^i_{s,j}(t) - \delta^i_{s,j}(t)) .$$

Where $\beta$ is a proportion coefficient and $\delta^i_{s,j}(t)$ is an end-to-end propagation delay which can be estimated by the minimum $RTT^i_{s,j}(t)$ observed from the history samples.

To achieve high efficiency objectives, the network management system needs to balance traffic between multiple paths. For example, if two paths are available to retrieve data, sending 40% of traffic on one path and 60% on another could lead to less congestion in the network and it can be formulated as a simple convex optimization problem (assuming that there are $N$ Interests in the queue carrying the requests for $N$ chunks of content $s$ and there are $\lambda$ available interfaces in node $i$ ):

$$\begin{cases} \min\limits_{\{n_1, n_2, \dots, n_\lambda\}} \max\{n_1 p^i_{s,1}, n_2 p^i_{s,2}, \dots, n_\lambda p^i_{s,\lambda}\} \\ n_1 + n_2 + \dots + n_\lambda = N \end{cases}$$

Obviously, when $n_1 p^i_{s,1} = n_2 p^i_{s,2} = \dots = n_\lambda p^i_{s\lambda}$ , we can easily get the optimal solution values $\{n^*_1, n^*_2, \dots, n^*_\lambda\}$. In this way, we can split the queue of Interests waiting in the buffer of a router into several sub-queue Interests.

## IV. EVALUATION

To demonstrate a disaster relief scenario, we build MANET on a real platform consisting of several smart cars equipped with Raspberry Pi. So far as we know, in similar fields, there are only a few research [18] [19] whose experiments are carried on real platform, while most adopt simulator (e.g. ndnSIM [20], the ONE [21]) to evaluate proposed schemes.

We used Raspberry Pi 3b to develop our MANET. We installed NFD in Raspberry Pis and implemented routing protocols and multipath forwarding strategy. Then we installed Raspberry Pis on the smart cars. Each smart car is equipped with a camera, an ultrasonic module, multiple sensors and other hardware. The detailed hardware parameters of raspberry pi are shown in TABLE I.

TABLE I. HARDWARE PARAMETERS OF RASPBERRY PI

| **Hardware** | **Parameter Value** |
|---|---|
| Chipsets | Broadcom BCM2837B0, 1.4GHz |
| Memory | 1GB LPDDR2 SDRAM |
| Wireless Adapter | 2.4GHz and 5GHz 802.11.b/g/n/ac wireless LAN |
| Power Input | 5V/2.5A DC |

### *A. Convergence Consideration*

To evaluate the proposed routing protocol, we focus on the speed of convergence. Two different scenarios were set to carry out the experiments.

As shown in Fig. 6, Node *A, B, F_1, F_2, F_3* have built an initial topology and they are relatively stable. In the first scenario, a new node enters the network and is discovered by *Node A* later. In the second scenario, a new node enters the network and is discovered by *Node F_3* later. In the two scenarios, new nodes both try to request content stored in *Node A*. We consider the earliest time when new entrant receives desired content as convergence time. For each scenario we carried out 12 experiments respectively and depicted the results in a box-plot (Fig. 7). It costs about 33 seconds and 47 seconds respectively to get the content in two scenarios. So the nodes are able to build a communication network by themselves.

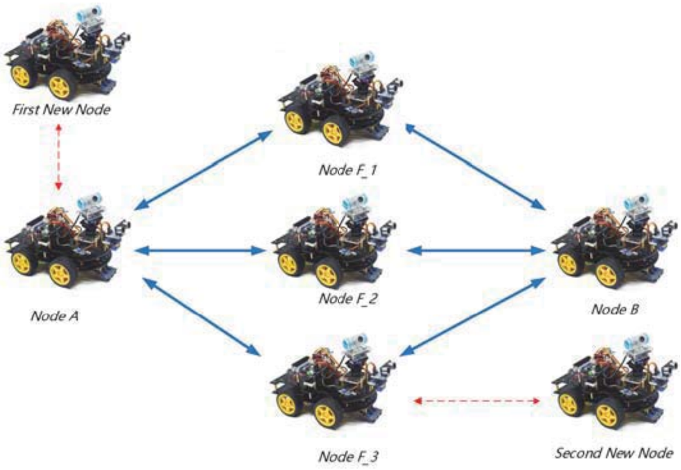


Fig. 6. Topology for evaluation

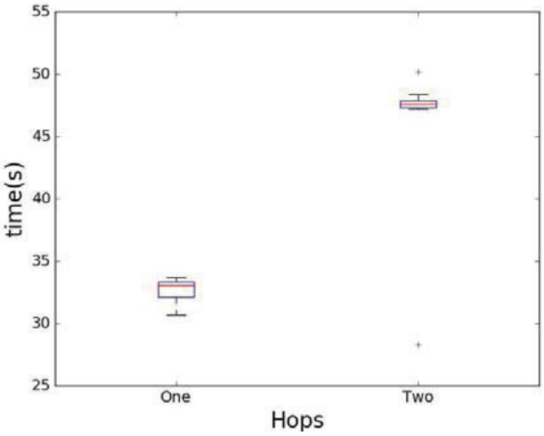


Fig. 7. Convergence time for two scenario

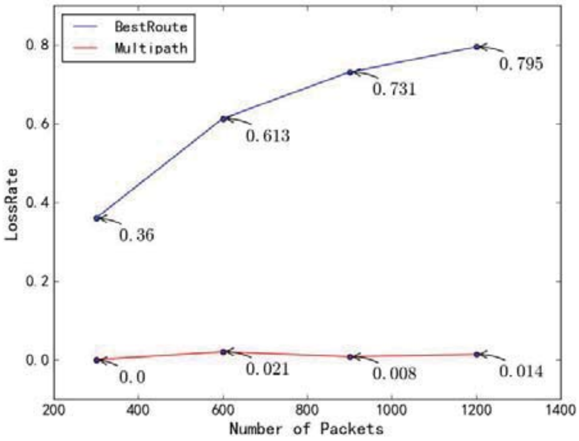


Fig. 8. Loss rate of BestRoute and Multipath strategy

### *B. The performance of multipath forwarding*

*1) High reliability:* The forwarding strategy to achieve high efficiency introduced in III.D is simply and undoubtedly true. Since our devices are in a good running condition and we lack the knowledge of underlying hardware, we have no good idea to implement natural packet loss. For the initial topology shown in Fig. 6, we deliberately set a delay in the *Node F_1* and packet passing through the wireless adapter will trigger the delay thus loss rate may increase due to timeout. The length of delay will increase with time. Therefore as shown in Fig. 8, where each Data’s size is 594B, the loss rate of multipath forwarding is normal since it can retrieve data normally though the normal paths while single path strategy suffers severe packet loss.

*2) High efficiency:* To evaluate the performance of splitting-queue forwarding strategies, we still use the initial topology of Fig. 6. Assume there is a long queue of Interest waiting to request a big file in *Node A*. Multipath forwarding strategy will guide Interests to three paths, which is equals to broaden the bandwidth. However, node using BestRoute strategy is impossible to achieve that bandwidth. As shown in Fig. 9, using multipath forwarding strategy saves more time.

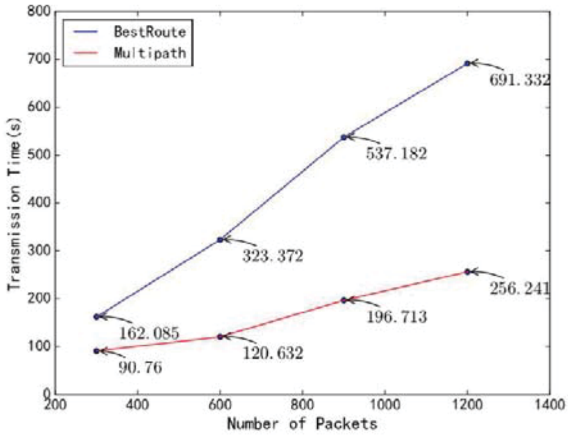


Fig. 9. The transmission time in BestRoute and Multipath strategy

## V. CONCLUSION

Communication is important after a disaster. In this paper, we propose a solution to adopt NDN for communication in the specific context of disaster relief. Since traditional TCP/IP protocol performs inefficiently in MANET, we argue to adopt NDN for communication after a disaster. The main challenges is the design of routing and forwarding scheme. Although most research focus on reactive routing protocols, we point out there are many in-build disadvantages for these protocols and may become invalid in our scenario. We propose a proactive routing protocol, which is also reactive-routing-enabled, and a multipath forwarding strategy.

Our routing protocol add a universal entry in FIB, hence some Interest can exploit a new path with the help of that universal entry. NDN natively supports multipath forwarding. We divide application into two classes requiring reliability or efficiency. By duplicating or splitting the queue of Interests, it can improve the reliability or efficiency of transmission.

Our experiments are carried out in the real platform. We design several scenarios to evaluate the performance of our solution. The experiments show our solution is able to build a communication network by nodes themselves, and supports multipath forwarding with high reliability or high efficiency. All these is beneficial for nodes to complete basic communication tasks and content distribution in a disaster relief scenario.

## ACKNOWLEDGMENT

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## REFERENCES

[1] Rehman R A, Kim B S. LOMCF: Forwarding and Caching in Named Data Networking Based MANETs[J]. IEEE Transactions on Vehicular Technology, 2017, 66(10): 9350-9364.

[2] Meisel M, Pappas V, Zhang L. Ad hoc networking via named data[C]//Proceedings of the fifth ACM international workshop on Mobility in the evolving internet architecture. ACM, 2010: 3-8.

[3] Yi C, Afanasyev A, Moiseenko I, et al. A case for stateful forwarding plane[J]. Computer Communications, 2013, 36(7):779-791.

[4] Zhang L, Afanasyev A, Burke J, et al. Named data networking[J]. ACM SIGCOMM Computer Communication Review, 2014, 44(3): 66-73.

[5] Alubady R, Al-Salman M, Hasan S, et al. Internet Protocol MANET vs Named Data MANET: A Critical Evaluation[C]// International Conference on Internet Applications, Protocols and Services. 2015.

[6] Liu X, Li Z, Yang P, et al. Information-centric mobile ad hoc networks and content routing: a survey[J]. Ad Hoc Networks, 2017, 58: 255-268.

[7] Meisel M, Pappas V, Zhang L. Listen first, broadcast later: Topology-agnostic forwarding under high dynamics[C]//Annual conference of international technology alliance in network and information science. 2010: 8.

[8] Amadeo M, Molinaro A. CHANET: A content-centric architecture for IEEE 802.11 MANETs[C]//Network of the Future (NOF), 2011 International Conference on the. IEEE, 2011: 122-127.

[9] Han H, Wu M, Hu Q, et al. Best route, error broadcast: a content-centric forwarding protocol for MANETs[C]//Vehicular Technology Conference (VTC Fall), 2014 IEEE 80th. IEEE, 2014: 1-5.

[10] Grassi G, Pesavento D, Pau G, et al. VANET via named data networking[C]//Computer Communications Workshops (INFOCOM WKSHPS), 2014 IEEE Conference on. IEEE, 2014: 410-415.

[11] Oh S Y, Lau D, Gerla M. Content centric networking in tactical and emergency manets[C]//Wireless Days (WD), 2010 IFIP. IEEE, 2010: 1-5.

[12] Yu Y T, Punihaole T, Gerla M, et al. Content routing in the Vehicle Cloud[J]. 2012:1-6.

[13] Yu Y T, Li X, Gerla M, et al. Scalable VANET content routing using hierarchical bloom filters[C]// Wireless Communications and Mobile Computing Conference. IEEE, 2013:1001-1014.

[14] Kalogeiton E, Kolonko T, Braun T. A multihop and multipath routing protocol using NDN for VANETs[C]// Ad Hoc NETWORKING Workshop. IEEE, 2017:1-8.

[15] Yi C, Abraham J, Afanasyev A, et al. On the role of routing in named data networking[C]//Proceedings of the 1st ACM Conference on Information-Centric Networking. ACM, 2014: 27-36.

[16] Detti A, Pisa C, Blefari-Melazzi N. Multipath forwarding strategies in Information Centric Networks with AIMD congestion control[J]. arXiv preprint arXiv:1412.2204, 2014.

[17] Tan X, Zhao Z, Cheng Y, et al. Flow-based NDN architecture[C]// IEEE International Conference on Communications. IEEE, 2016:1-6.

[18] Saxena D, Raychoudhury V, Becker C. Implementation and performance evaluation of name-based forwarding schemes in V-NDN[C]//Proceedings of the 18th International Conference on Distributed Computing and Networking. ACM, 2017: 35.

[19] Chowdhury M, Gawande A, Wang L. Secure Information Sharing among Autonomous Vehicles in NDN[C]//Proceedings of the Second International Conference on Internet-of-Things Design and Implementation. ACM, 2017: 15-25.

[20] Afanasyev A, Moiseenko I, Zhang L. ndnSIM: NDN simulator for NS-3[J]. University of California, Los Angeles, Tech. Rep, 2012, 4.

[21] Keränen A, Ott J, Kärkkäinen T. The ONE simulator for DTN protocol evaluation[C]//Proceedings of the 2nd international conference on simulation tools and techniques. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2009: 55.