Distance-aware Data Forwarding Protocol for Named Data Mobile Ad-hoc Network (NDMANET)

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Abstract. Information Centric Network (ICN) is a promising future networking architecture, while Named Data Networking (NDN) is regarded as ICN’s representative and authoritative scheme. In the recent past, applying ICN/NDN concept in mobile ad-hoc network (MANET), i.e. Named Data Mobile Ad-hoc Network (NDMANET), has attracted a plenty of research efforts. Compared to legacy IP protocol, NDN scheme is considered to be more robust and profitable to the node mobility and the dynamically changed topologies in the MANET domain. This paper focuses on NDMANET’s packet forwarding protocols, which to a large extent decides the efficiency of data dissemination and is a vital module of NDMANET. Firstly, the paper investigates and analyzes some existing packet forwarding protocols, which are widely accepted in NDMANET. On that basis, an innovative distance-aware data forwarding (DDF) protocol is elaborated for NDMANET, with the purpose of further enhancing its network performance. Comprehensive simulation experiments have been conducted and the results illustrate that the proposed DDF protocol can introduce considerable reduction in bandwidth and in energy consumption, with only slightly degrading the response ratio.

1. Introduction
MANET technology is designed to achieve data communication among nodes with mobility. Due to dynamic changing of network topology, and intermittent connections, MANET generally requires that there exists at least one complete end-to-end path between two nodes at some time for successful data transmission, and is highly vulnerable to packet loss and error in wireless environment. Therefore, an appropriate networking protocol is essential to MANET. TCP/IP protocol suite applied by the current Internet requires IP address to identify and locate a host, and then to maintain the end-to-end connection to realize reliable data delivery. That is however not suitable for MANET, considering the fact that MANET nodes are with mobility, and it is difficult to locate them by IP address.

At networking layer, legacy IP delivers data in the sender-driven (push) mode. ICN/NDN as a clean-slate approach, adopts the receiver-driven (pull) mode, and can enable two communication nodes to interact asynchronously with no need to establishing and maintaining an end-to-end connection. In addition, ICN/NDN’s in-networking caching technology enable each node to exploit full potentials of wireless channel’s broadcast nature, so to lower redundant requests and decrease content retrieval latency. Compared with IP, the above merits of ICN/NDN are consistent with MANET requirements.
According to [1], naming, routing (forwarding), caching, transport and security currently are top five research topics in NDMANET. Most existing packet forwarding schemes are originally proposed for fixed network, not dedicatedly designed and optimized for MANET. Therefore, aiming at further enhancing network performance, this paper explores innovative data forwarding strategies and elaborates a distance-aware data forwarding protocol for NDMANET. Performance evaluation indicates that the proposed protocol is capable of reducing redundant packets to be transmitted, decreasing bandwidth and energy resource consumption, with only slightly degrading response ratio. To summarize, the major contribution of this paper includes:

- Elaborates a distance-aware data forwarding protocol to improve NDMANET’s performance;
- Conducts comprehensive simulation experiments to evaluate the performance of the proposed distance-aware data forwarding protocol.

The remaining part of this paper proceeds as follows: First of all, Section 2 introduces the state-of-the-art followed by an in-depth background introduction in Section 3, which includes IP based MANET, NDN based MANET, as well as packet forwarding challenges in NDMANET. Then, in Section 4, as the major contribution, an innovative distance-aware data forwarding protocol is derived for NDMANET. Comprehensive performance evaluation by means of simulation for the proposed data forwarding protocol is conducted to demonstrate its effectiveness and efficiency in Section 5. Finally, Section 6 summaries the paper and gives the outlook.

2. Related work

Research on NDN’s application in MANET has recently gained much attention in academia. Packet forwarding protocol is one essential mechanism in NDN domain. There has been quite a lot of research efforts on it. The existing packet forwarding protocols can be classified into two types.

The first type is proactive forwarding based, which requires the content providers to periodically broadcast their own content name prefixes to other nodes, and consequently creates large overheads. Protocols of this type are only applicable to small-scaled and relatively stable networking scenarios. In [2], Yu et al. propose a protocol (BFR) using a bloom filter to advertise the name prefix of popular contents, which was applied in a typical VANET scenario. Kuang et al. in [3], propose a Content-Scent based architecture (CSAR), where different content is assumed to have its own content-scent. Each provider node periodically broadcasts a SCENTP that records the names of all the provided contents. However, the merit of low content transmission delay brought by the proactive forwarding protocols is offset by the overhead of maintaining routing states [4].

The second type is reactive forwarding based, which embodies the promising research direction in NDMANET. Protocols of this type do not need to maintain the routing table, while the flooding strategy is adopted to forward the interest packets. The blind flooding strategy is the simplest reactive forwarding protocol, which can well establish and maintain end-to-end route paths. However, it can cause broadcast storm problems [5] if not well controlled. Therefore, the x-aware based reactive forwarding protocols are proposed. Here, x-aware can be geographic-aware, neighbour-aware, distance-aware, etc. In [6], Lu et al. propose a direction-selective forwarding protocol, which can effectively reduce the redundant packets, but in the meanwhile can decrease the possibility of discovering potential content sources. In [7], Wang et al. increase geographic location information to content naming and only support location-related applications. BLOOGO (BLOOm filter based GOssip) [8] is a typical neighbour-aware protocol that determines whether to forward packets by comparing the containment relationships between neighbouring nodes. MADN (Multipath Ad-hoc Data Network) [9] uses a utility function to select the next hop forwarding node. RUFS (RobUst Forwarder Selection) [10] forwards neighbour information by prioritizing it. Neighbour-aware based protocols need to periodically exchange information with neighbouring nodes and need to make trade-offs between forwarding accuracy and forwarding overhead. LFBL (Listen First Broadcast Later) [11] is a distance-aware protocol. Each node in the network maintains a distance table. The distance information of the packets is equivalent. The distance measurement determines whether to forward the packets. CHANET (Content centric fasHion mANET) [12] introduces Int-Ack packet. When the
producer receives the interest packet, it will return the data object packet according to the information in the PRT. BREB (Best Route Error Broadcast) [13] is based on the improved forwarding protocol of LFBL and CHANGE. It maintains the distance-based design concept of LFBL protocol, integrates the three data packets of CHANET protocol, and increases the path recovery function. CHANET and BRBE are only suitable for relatively low-speed mobility scenarios. Therefore, more efficient data forwarding protocol are desired for further improving the NDMANET performance.

3. Challenges in NDMANET

3.1. IP based MANET
MANET is extremely vulnerable in wireless environment featured of signal interference, fading and shadowing. In data link layer (L2), media access mechanisms such as CSMA/CA, TDMA, etc. are adopted to avoid access violation, and to make the most efficient use of the wireless broadcast channels. In networking layer (L3), legacy IP protocol is naturally employed due to its highly successful application in fixed networks. However, IP is ill-suited for MANET due to the following reasons: Firstly, IP based MANET belongs to the host-centric networking (HCN) domain. IP address is not only the node’s identifier but also the locator representing its topological locations. Once a node moves out of the ad-hoc setting, it will fail to be located and then IP addresses aggregation will not be feasible [14], Secondly, nodes of highly mobility suffer from a large overhead to keep the binding between the node and its current address. Thirdly, the sender-driven transmission fails to utilize the other receivers to take over the forwarding when the intended receiver may not be expected any more.

3.2. NDN based MANET
It is an elemental demand for ad hoc networking to support nodes mobility. Appling NDN scheme in MANET can naturally satisfy this requirement. The major reasons are given below: Firstly, different from HCN, NDMANET employs unique name to identify with each Data unit, and it enables the applications to publish and consume Data directly through its name without being providing the network layer address. Secondly, in the HCN domain, TCP/IP session are required to be constantly reestablishments due to intermittent links between two communication moving nodes, which introduce considerably large overheads and delays. While NDMANET’s receiver-driven mode makes sessions established for communication nodes unnecessary anymore. Thirdly, NDMANET separates data from physical node to make the data reusable, plus with the in-network caching mechanism, which further accelerates content transmission by means of local caching of previously retrieved data.

3.3. Challenges in content forwarding scheme of NDMANET
Receiver-driven mode based content forwarding scheme can fully use the broadcasting nature of wireless channels. However, there exist some challenges for broadcasting transmission, such as broadcast packets redundancy and collisions, which will eventually introduce bandwidth resource wastage, etc. Therefore, it is necessary to solve the broadcasting issues for enhancing the forwarding performance of typical NDMANETs.

4. An innovative distance-aware data forwarding protocol for NDMANET

4.1. Important factors of packet forwarding protocols in NDMANET
Due to the high dynamicity of MANET topology, designing packet forwarding protocols should minimize the dependence on fixed topology, and should pay attention to the logical process of the multi-faceted information obtained by networking nodes. Besides, other factors should also be considered includes: Firstly, avoiding to generate unnecessary packets. Since the energy and storage resources of mobile nodes are typically limited, introducing additional packets will increase energy and computation resource consumption; Secondly, protocol should be concise and robust. NDMANET nodes are divided into three roles, namely producer, consumer, and intermediate forwarding node. The
interaction between nodes of the three types should be effective and efficient; last but not least, forwarding decisions should be calculated locally at intermediate nodes based on local information obtained through inter-nodes packet interactions.

4.2. Principle of distance-aware data forwarding protocol

4.2.1. Packet modification and table description. To keep the protocol concise and to reduce extra traffic and processing cost introduced by new packets, the proposed DDF protocol does not introduce any new packet formats except the Interest and Data packet originally from NDN. However, some necessary modifications to the packet formats are made for the proposed protocol, and are shown in figure 1. Table 1 explains the meaning of each field.

![Figure 1. The modified packet formats for DDF protocol.](image)

Table 1. Field description for the modified packet formats.

|                | Interest Packet | Data Packet |
|----------------|-----------------|-------------|
| **Name**       | Content name    | Content name |
| **Nonce**      | Random number used to identify duplicate Interest packet | Distance between data packet and producer. When data packet is forwarded once, the value is incremented by one |
| **Distance**   | Distance between Interest packet and consumer. If Interest is forwarded once, the value is added by one | CID Record the target consumer identity information. |
| **SID**        | Records unique identifier of source node (MAC addresses or application ID) | ED Record the expected distance from the producer to the consumer |
| **Seq**        | Monotonically increasing integer, which records the order of interest packets | Tag Forwarding status of packet (0 represents the normal state; 1 indicates the data packet is in a state to be discarded) |

In order to record the distance information used for making forwarding decisions, a Consumer Distance Table (CDT) is introduced to each forwarding node, and to record the distance between the nodes and the consumers. The structure of the table is shown in figure 2.

![Figure 2. Format of the Consumer Distance Table (CDT).](image)

4.2.2. Interest packet processing. The consumer assigns its identity information to the SID field and set the sequence number value for the Seq field of the Interest packet before sending it out. The
Distance field of the Interest packet is initialised as 0. In the process of flooding Interest packets, the Interest packet processing algorithm running on the forwarding nodes is shown in figure 3.

| Interest packet processing |
|----------------------------|
| 1: Interest packet preprocessing |
| 2: if Name match CS then |
| 3: update CDT |
| 4: return Data packet |
| 5: else |
| 6: if Name match PIT then |
| 7: update CDT |
| 8: drop Interest packet |
| 9: else |
| 10: update CDT |
| 11: add new PIT item, forward Interest packet |
| 12: end if |
| 13: end if |

| Data packet processing |
|------------------------|
| 1: Data packet preprocessing |
| 2: if Name match PIT then |
| 3: Tag=0 |
| 4: add new CS item |
| 5: delete PIT item |
| 6: if ED - D_pro >= D_con then |
| 7: forward Data packet |
| 8: else |
| 9: drop Data packet |
| 10: end if |
| 11: else |
| 12: if Tag==0 then |
| 13: if Name match CS then |
| 14: drop Data packet |
| 15: end if |
| 16: else |
| 17: Tag=1 |
| 18: add new CS item |
| 19: delete PIT item |
| 20: Distance = Distance-1 |
| 21: forward Data packet |
| 22: end if |
| 23: end if |

**Figure 3.** Interest packet processing algorithm.  
**Figure 4.** Data packet processing algorithm.

CDT will create a new entry for the Interest packets that cannot match the content name. If an Interest packet matches the CDT, the CDT will be updated based on the Seq field. If the Seq value in the latest received interest packet is smaller than the Seq in the CDT, the interest packet is considered to have expired, so the CDT is not changed and the Interest packet is discarded. If the Seq value is greater than the Seq in the CDT, the interest packet is modified to carry the newest distance information, namely the Seq field and the Distance field in the CDT are updated to the Seq value and the Distance value in the interest packet. If Seq is equaled, the smaller Distance value in Interest will be updated in CDT. In particular, the node will set a timer for each table item of the CDT. The timeout period is $T$. If the entry of CDT is updated, the timer will be reset; if the table item of the distance table is updated, the timer will be reset. If the entry has not been updated after time $T$, it is considered invalid, and the entry will be deleted immediately.

4.2.3. **Data packet processing.** After flooding Interest packets, CDT of all the nodes are updated. The qualified producer will match the related entry in the CDT and assign the Distance value to the ED field when Data packet is generated. The initial values of the Tag field and the Distance field in Data packet are both 0. The intermediate node will determine whether or not to forward the Data packet by equation (1).

$$ED - D_{pro} >= D_{con}$$  \hspace{1cm} (1)

$D_{con}$ represents the Distance value in the CDT, $D_{pro}$ represents the Distance field in the packet. Equation (1) is adopted to determine whether the Data packet is in the shortest return path. If so, the returning delay can also be assumed to be shortest and the path is optimal. Thus, the node will forward the Data packet. Otherwise, the Data packet will not be forwarded. Equation (1) effectively filters the redundant forwarding packets caused by flooding, and consequently reduces the transmitted traffic.
In order to improve the response rate and to avoid the problem that node may discard the Data packet directly when it cannot match the PIT entry, in the proposed protocol, intermediate nodes will try to forward the Data packet once, and the Tag field of the Data packet will be set as 1. If PIT can be matched by the Data packet after the procedure mentioned above, the Tag field is set to be 0. If PIT still cannot be matched, the Data packet is then discarded. The above algorithm is given in figure 4.

4.3. Advantages and Disadvantages
The advantages of the derived DDF protocol lie in the fact that it can guarantee the stability and reliability of communications between consumers and producers in high dynamic conditions. At the same time, the proposed protocol retrieves Data packet over the shortest distance path, which can reduce the consumption of bandwidth, energy, cache resources, as well as chance of conflicts caused by flooding packets. Since the DDF protocol updates the CDT with flooding the Interest packets, which generates additional traffic, and broadcast storms may still occur in the case of dense consumer situations. This protocol does not take into account acquisitions of distance information from unintentionally monitored packets, which has little impact on network performance. The continuous requests of different consumers may reduce the retrieving efficiency of network distance information.

5. Performance evaluation by means of simulation

5.1. Performance metrics
The BF and BREB forwarding protocols are two most widely deployed forwarding protocols, which are compared with the elaborated DDF protocol. Five performance metrics (RR, BC, ND, EC, CRC) are chosen to be evaluated, as is defined in table 2.

| Metric (Abbreviation) | Description |
|-----------------------|-------------|
| RR (Response Ratio)   | Ratio of the number of Data packets received by the consumer to the number of Interest packets sent by the same consumer |
| BC (Bandwidth Consumption) | Total amount of traffic transmitted by all the networking nodes |
| ND (Number of Data packets) | Total number of Data packets transmitted in the network |
| EC (Energy Consumption) | Total energy consumption for nodes to send interest & data packets |
| CRC (Computation Resource Consumption) | Total computation resource consumption for nodes to process interest and data packets |

5.2. Simulation introduction
The proposed DDF protocol is implemented in ndnSIM / NS-3 network simulator. In order to investigate node mobility’s impact on the performance of the proposed protocol, the simulated geometry scale is set to be a square of 1500m*1500m, and the maximum transmission range for each node is assumed to be 200m. A random rectangular positional allocator is used to assign the initial position of each node, while Random Waypoint Mobility Model [15] is used to simulate the motion trajectory of the nodes. The simulation time is 200 seconds.
5.3. Results analysis

Figure 5. Result of Response Ratio

Figure 6. Result of Bandwidth Consumption

The aforementioned three packet forwarding strategies, namely BF, BREB and DDF forwarding protocols are simulated respectively. To ensure the three protocols are comparable, random numbers in the mobile model and the distribution model are generated based on the same random seeds. The simulation results of the Response Rate of the three protocols at different speeds are shown in figure 5. The Response Rate of DDF and BF are close at different speeds. This reflects the accuracy of the distance information generated by the DDF protocol, indicating that the ability to improve the distance perception can be improved by flooding interest packets. The Response Rate of BREB decreases with the increase of node moving speed. This is because BREB cannot respond to topology changes in time, resulting in untimely update of distance information. Figure 6 shows the bandwidth usage of the three protocols at different speeds. DDF has the lowest bandwidth consumption, which means that nodes occupy less bandwidth and means fewer collisions. This explains to some extent, in figure 5, why the response rate of BF will fall back when the speed is close to 35 m/s. BREB will trigger the adaptive routing adjustment algorithm after the topology changes, which will increase the bandwidth usage, thus the bandwidth growth of BREB is relatively volatile.

Figure 7. Result of ND

Figure 8. Result of EC

Figure 9. Result of CRC

Figure 7 shows the total number of Data packets sent by the three protocols at different speed. Experimental results intuitively indicate that distance perception can effectively reduce the redundant data packets brought by BF. The number of data packets sent by the BF and the DDF protocols does not change much as speed increases. BREB protocol can effectively reduce redundant data packets at low speeds, while the relatively slow distance update algorithm introduces negative influence on the performance of BREB as the speed continues to increase. Figure 8 and 9 show the energy and computation resource consumption of the three protocols at different speeds. The DDF protocol updates the distance information by flooding interest packets which consumes additional energy and computation resources. The simulation results show that the DDF protocol is superior to the BF and the BREB protocols on energy consumption. However, at low speed situations, the computation resource consumption of the DDF protocol is higher than that of the BREB protocol, although the difference is getting smaller as the speed increases. On the other hand, the DDF protocol always performs better than the BREB protocol regarding resource utilization.

To conclude, the proposed DDF protocol can effectively reduce redundant Data packets in the network, thereby reducing bandwidth and energy resource consumption. The fast update of the distance information by flooding Interest packets ensures the timeliness of the distance information,
which greatly improves the response ratio of the distance sensing strategy. Although flooding Interest packet consumes additional computation resources, it is beneficial at high speeds.

6. Summary and outlook

NDMANET has attracted quite a lot of research efforts in the past few years. This paper investigates its data forwarding protocol, a vital factor influencing MANET performance. A novel DDF Protocol is elaborated aiming to further reducing redundant packets to be transmitted, decreasing bandwidth and energy resource consumption in MANET scenario. According to the results of comprehensive simulation experiments, the proposed DDF protocol outperforms the legacy BREB and BF approaches, which indicates the proposed protocol is effective and efficient.

The next step of this work could focus on the real-time video streaming in NDMANET, which is more challengeable compared with other applications. On the basis of the elaborated DDF protocol, it is valuable to explore some other innovate approaches to enhance the QoS & QoE of real-time video applications, including both video-on-demand and live broadcasting, in typical NDMANETs.

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References

[1] Liu X, Li Z, Yang P and Dong Y. 2016. Information-centric mobile ad hoc networks and content routing: a survey. Ad Hoc Networks
[2] Yu T, Thomas P, Mario G and Sanadidi M Y. 2013. Content routing in the Vehicle Cloud. Military Communications Conference IEEE
[3] Kuang, J and Shun, Z.Yu. 2015. CSAR: A Content-Scent based Architecture for Information-Centric mobile ad hoc networks. Computer Communications
[4] Matteo V, Ivica R, Uichin L, Lloyd G and Volker H. 2011. On the design of content-centric MANETs. Eighth International Conference on Wireless On-demand Network Systems & Services IEEE, 2011:1-8
[5] Tonguz O K, Wisitpongphan N, Parikh J S, Bait F, Mualiget P and Sadekart V K. 2006. On the Broadcast Storm Problem in Ad hoc Wireless Networks. International Conference on Broadband Communications. IEEE
[6] Lu Y, Zhou B, Tung L C, Gerla M, Ramesh A and Nagaraja L. 2013. Energy-efficient content retrieval in mobile cloud. Workshop on Sigcomm
[7] Lucas W, Alexander A, Romain K, Rama V, Ryuji W and Lixia Z. 2012. Rapid traffic information dissemination using named data. Proceedings of the 1st ACM workshop on Emerging Name-Oriented Mobile Networking Design - Architecture, Algorithms, and Applications - NoM ’12
[8] Angius F, Gerla M and Pau G. 2012. BLOOGO: BLOOm filter based GOssip algorithm for wireless NDN. Proceedings of the 1st ACM workshop on Emerging Name-Oriented Mobile Networking Design - Architecture, Algorithms, and Applications ACM
[9] Angius F, Bhiday A, Gerla M and Pau G. 2013. MADN - Multipath Ad-hoc Data Network prototype and experiments. Wireless Communications & Mobile Computing Conference, IEEE
[10] Ahmed S H, Bouk S and Kim R D. 2015. RobUst Forwarder Selection in Vehicular Content-centric Networks. IEEE Communications Letters 19.9(2015):1-1
[11] Michael M, Vasileios P and Lixia Z. 2010. Listen First, Broadcast Later: topology-agnostic forwarding under high dynamics. Army Research Laboratory and the U.K. Ministry of Defence, W911NF-06-3-0001
[12] Amadeo M and Molinaro A. 2012. CHANET: A content-centric architecture for IEEE 802.11 MANETs. 2011 International Conference on the Network of the Future, IEEE
[13] Bettstetter C, Resta G and Santi P. 2003. The Node Distribution of the Random Waypoint Mobility Model for Wireless Ad Hoc Networks. IEEE Transactions on Mobile Computing 2(3):257-269
[14] Han H, Wu M, Hu Q and Wang N. 2014. Best Route, Error Broadcast: A Content-Centric Forwarding Protocol for MANETs. Vehicular Technology Conference, IEEE
[15] Bettstetter C, Resta G and Santi P. 2003. The Node Distribution of the Random Waypoint Mobility Model for Wireless Ad Hoc Networks. IEEE Transactions on Mobile Computing, 2(3):257-269