

Location based Data-centric Forwarding for Mobile Ad-hoc Networks

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Abstract—With the ever-increasing usage and deployment of mobile devices, mobile ad-hoc networks have become more and more prevalent in replacing centralized networks. However, high mobility of nodes can lead to challenging performance issues, such as high packet loss, frequent path failures causing high route-reinitiating overheads, and significant data retrieval delay. Named Data Networking (NDN) offers an alternative solution to these problems. But, existing approaches still have many issues and can be further improved. This paper proposes a novel location-based approach that aims to address existing challenges of using NDN in mobile ad hoc networks and improve the performance of existing works. The simulation results presented in the paper prove that our approach is very much feasible.

Index Terms—forwarding strategy, MANET, named data networking, network simulations

I. INTRODUCTION

Named Data Networking (NDN) [1] is an information-centric Internet architecture designed to tackle various unsolved challenges in the existing TCP/IP Internet. Many challenges can be found during network deployment for ad-hoc wireless networks, such as involving various communication protocols, insufficient infrastructure routing support, and deteriorated performance due to an unstable network environment.

While existing NDN forwarding techniques can partially address these issues, there is still a lot of room for improvement. Broadcasting, while being an effective mechanism for NDN in an ad-hoc wireless network environment, can cause strain on a limited-bandwidth network. Adaptive methods may help with limiting bandwidth usage caused by broadcasting. However, they can incur significant overhead due to complicated set-up and route reconfiguration, especially for volatile and mobile networks.

This work aims to improve the performance of current NDN based data forwarding protocols in a mobile ad-hoc environment by using neighboring nodes' location information to determine the most reliable path to forward Interest packet. To demonstrate this, we conducted comprehensive simulations to compare the packet delivery performance of our proposed approach with the existing broadcast-based NDN forwarding protocol.

The rest of this paper is organized as following. Section II presents other related researches. The design of the proposed system is detailed in section III. In section IV, our approach is evaluated and compared with existing solutions. Lastly, section V summarizes our contributions and outlines future works.

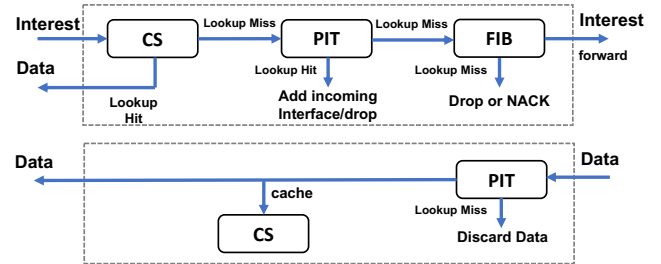


Fig. 1: Normal Forwarding pipeline in a NDN node

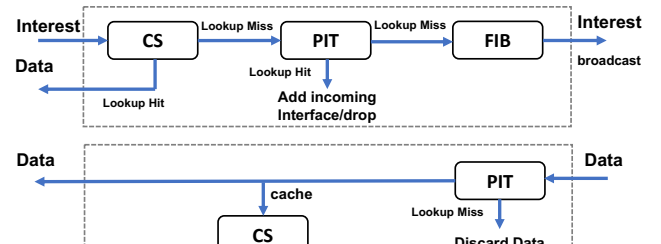


Fig. 2: Broadcasting Forwarding pipeline in a NDN node

II. RELATED WORK

Originally, NDN utilizes the reverse paths between Consumer and Producer to deliver Data [2]. However, in a mobile ad-hoc environment, these reverse paths can be easily broken down when consumer nodes start moving away from their original position. While NDN has a natural advantage in dealing with this issue via in-network caching (to shorten the distance between consumers and data) [3] [4], it raises other issues as well such as which data should be cached/dropped, considerable data retrieval delays due to having the Interests going all the way back to the data source or reestablishing a new Data path if the requested Data is not cached anywhere [5]. Also, this does not fully solve the mobility issue.

The most common NDN forwarding strategy for mobile ad-hoc network is broadcasting /flooding. An NDN broadcast-based forwarding strategy follows the general NDN architecture [1]. An NDN consumer sends an Interest with a name when it wants to retrieve data. Upon receiving the Interest, a node will look at its Content Store (CS) and replies with data on a name match. Otherwise, the Interest is passed to the Pending Interest Table (PIT). If there is an entry with the

same name in the PIT, the Interest is discarded, and the entry is updated to include the new request. If no entry in the PIT matches the Interest's name, a new entry is created with the incoming interface and passes the Interest to its Forwarding Information Base (FIB). Next, the node performs the longest common prefix match to existing FIB prefix entries. With the general NDN architecture, the node forwards the Interest through the associated interface(s) to the next hop node(s) if a match is found. If a match is not found, it either drops the Interest or sends a NACK (negative acknowledgment) back. This will inform the other nodes that a route through this node is unavailable. However, this is not true for a broadcast-based (or flooding) NDN strategy. The FIB hit/miss status is ignored in this case; all Interests are broadcast after passing through the PIT. The rationale behind this is that it can potentially increase data retrieval possibility through multiple possible paths between a consumer and data node(s). This scenario also has no NACK, as every packet transmission is broadcast. When a node receives data, it will first check the PIT. If a match is found, the data is passed to CS; otherwise, the data is dropped. After updating CS, the data is forwarded to the associated node based on the existing PIT entry. The PIT entry is then clear afterward. The main disadvantage of broadcasting/flooding in NDN over mobile ad-hoc network is that it can lead to a high possibility of collision and channel contention in the network due to high number of Interest transmissions (and retransmissions caused by nodes' mobility).

To minimize the negative effect of broadcasting Shi *et al.* proposed NDN self-learning [6]. Similar to IP-AODV [7], a consumer will first broadcast discovery Interests until information about the next hop toward data is learned. When it receives the data which travels as unicast, the consumer will switch to unicast Interests to a next-hop in the determined path (via the discovery Interests). This approach, however will not work very well for mobile ad-hoc networks as only the consumer node makes discovery decisions. Also, it can suffer from many application-level timeouts and is not very reactive to mobility within the network. [8] - [9] also discuss NDN routing and forwarding protocols for mobile ad-hoc networks. The performance of these approaches, however, can be further improved.

Another approach to reduce the number of Interest transmission/retransmission caused by broadcasting/flooding is via controlling the forwarding rate of each participating nodes. NAIF (Neighborhood-Aware Interest Forwarding) [10] uses data retrieval statistics to decide whether to lower or increase the Interest forwarding rate. However, this can incur high overheads and will not react well to sudden changes in network. [11] uses a counter-based suppression mechanism to reduce the forwarding rate. Before forwarding Data/Interest, a random time interval is introduced. During this time period, if the node notices that the same packet is being transmitted by another node then the packet will be dropped.

[12] uses geographic positions of producer nodes and the remaining energy of neighboring nodes to determine which node to forward Interest packets to. The probability of a neighboring node being chosen to forward Interest packets to is calculated by balancing its distance to the producer node

and its residual energy. Because of the focus on limiting energy consumption, this does not guarantee optimal route to producers. Also, this approach does not consider the mobility of the nodes in the network.

III. THE PROPOSED FRAMEWORK

This section will list the challenges of designing an NDN framework for mobile ad-hoc networks and detail how we plan to address them with our proposed system.

A. Challenges

The environment of edge networks is usually very unstable, which could lead to packets lost, disruption in the communication link, and dynamically changed topology. To address this, existing approaches [6] [13] choose to broadcast Interest as the core mechanism as it is very simple and effective to discover content with broadcasting in NDN. NDN is able to detect and drop looped Interests at the forwarding plane - an NDN node can safely forward Interests to any face in any topology without worrying about creating loops. However, Interest broadcasting takes up a significant amount of network and device resources. Another issue with this is that different types of communication protocols may have different route-finding performances via broadcasting. For example, Ethernet and UDP communication interfaces perform significantly worse than a unicast interface in a Wi-fi network.

Lastly, many devices involved in edge networks have mobility and limited resources, so it is difficult for them to assume the roles of forwarders and have the capability to perform in-network caching.

B. System Architecture

To address the impact of nodes' mobility in mobile ad-hoc networks, we take into account the position of the neighboring nodes when choosing which hop to forward Interests to. We assume that nodes are equipped with a global position system (GPS) and connect to each other using an omnidirectional antenna. Each node will regularly send discovery Interests with its current position to its neighbor nodes. Based on this information, mobile nodes can compute the speed and distance with respect to the neighbor nodes and will use this information to determine which path to forward the Interests.

1) *Nodes Distance Calculation:* Mobile nodes' location, speed, and direction are changed dynamically in MANETs. We calculate the Euclidean distance between two neighbor nodes to determine whether the nodes are moving toward each other or away from each other. This information will then be used to rate the next hop to forward the Interests to.

Suppose there are two mobile nodes n_1 and n_2 with a transmission range of r . Nodes n_1 and n_2 are moving at the speed of V_{n_1} and V_{n_2} , respectively.

The distance between n_1 and n_2 - D_{n_1, n_2} at a time t can be calculated as:

$$D_{n_1, n_2}(t) = \sqrt{(X_{n_2(t)} - X_{n_1(t)})^2 + (Y_{n_2(t)} - Y_{n_1(t)})^2}, \quad (1)$$

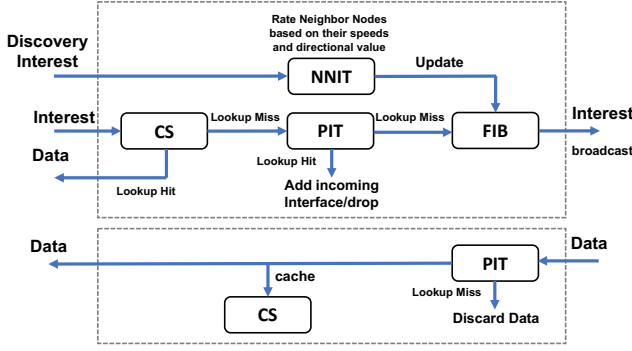


Fig. 3: NDN pipeline for our proposed system with the added Neighbor Nodes Information Table

where $(X_{n_1(t)}, Y_{n_1(t)})$ and $(X_{n_2(t)}, Y_{n_2(t)})$ are the locations of n_1 and n_2 at a time t , respectively.

At $(t + \Delta t)$ time, the distance between n_1 and n_2 , $D_{n_1, n_2}(t + \Delta t)$ can be calculated as:

$$D_{n_1, n_2}(t + \Delta t) = \sqrt{(X_{n_2(t+\Delta t)} - X_{n_1(t+\Delta t)})^2 + (Y_{n_2(t+\Delta t)} - Y_{n_1(t+\Delta t)})^2}, \quad (2)$$

If we define mobility as the average change in distance between all nodes over that period of time, then it can be expressed as a function of speed and movement pattern. The speed of a node at a time t can be calculated as follows:

$$V(t, t + \Delta t) = \frac{|(X_2 - X_1) + (Y_2 - Y_1)|}{(t + \Delta t) - t} \quad (3)$$

By these formulas, each node can compute its speed and distance from its neighbors at any given time.

After determining the distance between n_1 and its neighbors at t and $(t + \Delta t)$, we can determine whether n_1 is heading toward or away from its neighbors. If $D_{n_1, n_2}(t)$ is larger than $D_{n_1, n_2}(t + \Delta t)$, then nodes n_1 and n_2 are closer to each other within the time interval between t and $(t + \Delta t)$. Hence, the two nodes are heading toward each other for this interval. On the other hand, if $D_{n_1, n_2}(t)$ is less than $D_{n_1, n_2}(t + \Delta t)$, the nodes are moving away from each other and the nodes have a high probability of being disconnected.

2) *Neighbor Nodes Information Table - NNIT*: When a node receives discovery Interests, it will store the sending node's information in a separate table. This table contains two fields: the neighbor nodes' speed and the neighbor nodes' direction. The direction value is calculated using equation 2 and 3. If the nodes are heading toward each other and the distance between the two nodes is constant, the direction value is set to one. Otherwise, the direction value is set to 0.

Each of the neighbor nodes in the table will then be rated based on these two values. Suppose a neighbor node has a direction value of 1 and a lower speed. In that case, it will be ranked higher as a connection with a node that moves slower and heads toward or in the same direction will have a higher probability of lasting longer.

IV. EVALUATION

This section analyzes the performance of our approach in comparison with NDN flooding. We use packet delivery ratio, end-to-end delay, and response time as performance metrics.

- 1) *Packet Delivery Ratio*: The ratio of the number of data packets successfully received at the consumer application with respect to the number of unique Interests sent.
- 2) *End-to-end Delay*: The average round-trip time measured at the consumer applications.
- 3) *Response Time*: The average time it takes for a consumer application to receive the first data packet with respect to the Interest sent.

A. Experimental Set-up

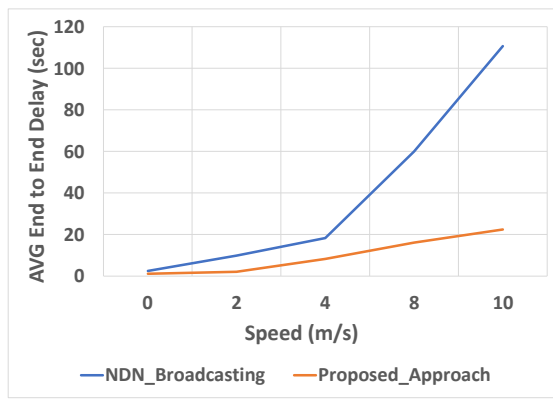
To verify the theoretical results, we devise a series of simulations using ndnSim simulator [14]. For our simulations, we place the nodes randomly within an area of 200m x 250m for 20 nodes network. Each node has a fixed transmission range of 50 meters in diameter. Each node has only one wireless interface communicating over a single channel of IEEE 802.11a at 24Mbps. The system consists of 4 consumers and 2 producers, with the other nodes serving as forwarders.

Each consumer will request 50 different data packets of 512 bytes, each using a constant bit-rate application. The consumers will start randomly during the 5 seconds period after the simulation starts. We apply the random waypoint mobility model for the nodes' mobility. The speed of the nodes is set to be 0m/s (stationary) first, then changed to be 2m/s, 4m/s, 8m/s, and 10m/s for each scenario.

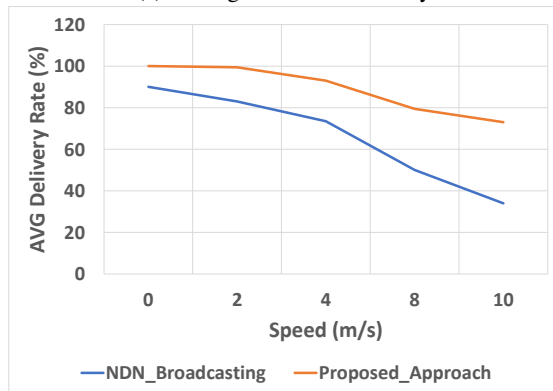
B. Results

Figure 4 shows the result of experiments for our proposed system and NDN broadcasting in a 20 nodes network. At lower speeds (stationary to 4m/s), our approach performs better than NDN broadcasting across all metrics. However, it is not by a more significant margin, especially for the end-to-end delay and response time. The result of the packet delivery rate, however, clearly shows the disadvantage of the broadcasting approach. For the scenarios in which the nodes are either stationary or moving at lower speed, if the nodes are close together, broadcasting/flooding interest packets can lead to high frequency of packet collision in the network which in turn will result in lower delivery rate. When the nodes start moving faster, if the nodes are moving away from each other, it can help with the delivery rate of the broadcasting strategy as there are more spaces between each node (which can lead to less packet collision). However, this will come at the cost of introducing more traffics to the network.

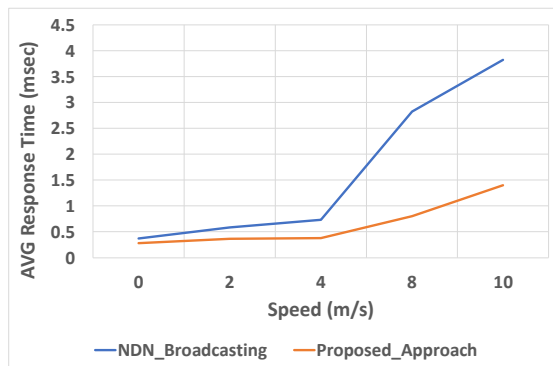
When we change the mobile nodes' moving speed from 4m/s to 8m/s, NDN broadcasting suffers a sharp increase in both response time and end-to-end delay while the change of speed has a much lesser effect on our approach's performance. The increase in response time and end-to-end delay in our approach is due to the slight overheads incurred by recalculating the neighbor information when neighboring nodes start moving away from their original positions.



(a) Average End-to-end Delay



(b) Average Packet Delivery Rate



(c) Average Response Time

Fig. 4: Effect of mobility in a 20 nodes network for the proposed work and NDN broadcasting

V. CONCLUSION

This paper presented a novel location-based NDN forwarding scheme for mobile ad-hoc networks. As shown in the paper, we proved that our approach could reduce network latency while improving data retrieval comparing to existing works. Due to the limited scope of the experiments, we cannot verify the scalability of the framework. As part of our future work, we plan to address this by evaluating our approach with real-life and larger-scale network.

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