Directed-Propagation Link-State Routing Protocol for Information-Centric Networks *

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ABSTRACT

This paper presents the design of *Directed-Propagation Link-State Routing Protocol* (DPLSR), which tries to address the issue of prefix flooding storm in NDN Link-state Routing Protocol. Since the number of data object is several order of magnitude of that of routers, legacy Link State Advertisements (LSAs) flooding model is no more appropriate in NDN. This paper proposes a LSA directed-propagation scheme that LSA messages are only forwarded towards Root anchor, not flooding. Upon requesting a data object, a Look-up message is sent towards Root anchor. When it encounters a router with accroding anchor and prefix information, an anchor list is returned. Users are able to access the nearest copy or build one or multi-path connections to the anchors. In DPLSR, messages are propagated along some paths, and only parts of router store prefix and anchor information. Thus, the communication overhead and prefix storage are reduced significantly compared with the existing NDN routing protocols. Simulated experiments also verifies the performance gain of DPLSR.

CCS Concepts

•**Networks** → *Network protocols;*

Keywords

ICN;name-based content routing;link-state routing

1. INTRODUCTION

The current Internet architecture was designed many years ago to meet the demand for sharing limited, static contents. As the number of contents in the Internet increases dramatically and dynamically, however, the majority of Internet usage turns to content retrieval and distribution, which means that clients care more about content itself rather than its location. ICN architecture is proposed responding to this tendency, in which every content in the network is independent from its location. Contents are retrieved and distributed based on their names rather than host addresses. Name resolution and name-based content routing are two mechanisms for ICN to provide efficient, mobile, and scalable content retrieval. In recent years, Content Centric Networking (CCN)[1] and Named Data Networking (NDN)[3] are designed. However, how to addressing content and name-based routing are still big challenges for ICN.

In this paper we propose a *Directed-Propagation Link State Routing* (**DPLSR**) protocol which disseminates prefix information only along some paths, not flooding. Router does not need global views of prefix, it exploits legacy topology routing to assist name-based routing with small overhead. Each prefix is binding with one and only one Root anchor. Any node storing this data object just sends prefix LSA messages along the path directly towards Root anchor using topology routing. Only en-route nodes record anchor and prefix information. Then in DPLSR only topology information is global, while prefix information is stored in some routers. Routers also have only partial prefix information. Assisted by topology routing, DPLSR is able to access the nearest copy by name, and build one or multi-path connections to anchors. At the same time, the communication overhead and storage space are reduced significantly.

This paper is organized as follow: Section 3 presents **DPLSR** (*Directed-Propagation Link-State Routing*), a routing protocol for ICN. Section 4 presents the results of simulation experiments implementing to compare DPLSR to other LSA-broadcasting approaches in communication overhead, storage overhead and propagation delay. Finally we conclude this paper in Section 5.

2. RELATED WORK

There are a number of ICN protocols proposed to cope with name-based routing. Most of them are some transformation of legacy topology routing protocol.

NLSR (Named-data Link State Routing) [7] is one pioneering work addressing this issue. It propagates topology link-state information and prefix-related information separately, and proposes a hop-by-hop synchronization protocol to reduce the overhead of network-wide flooding. However due to every node has global view of prefixes and anchors, the communication and storage overhead is still high.

DCR (Distance-based Content Routing) [5] is another name-

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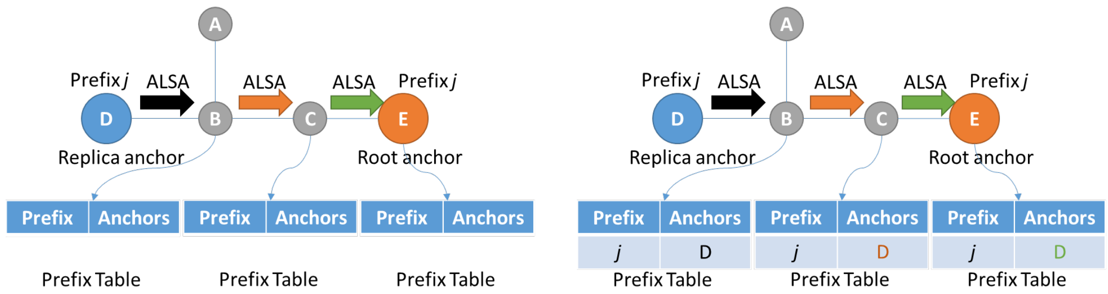


(a) Replica anchor sends out a directed ALSA towards Root anchor

(b) En-route routers changes PAS accordingly

Figure 1: LSA directed propagation phase

routing approach, which come up with only disseminating the shortest distance messages with neighbors to a given prefix. It is more like a distance-vector routing protocol, not like link-state protocol. Also multi-Instantiated Destination Spanning Tree (MIDST) is proposed to organize all the anchors of a given prefix in the network. Its communication overhead is less than NLSR, but it still needs global view of all prefix as NLSR which leads to high overhead.

LSCR (Link-State Content Routing) is proposed in 2015, which is a new approach for name-based routing. It uses a flooding mechanism to propagate link-state information about topology, but propagates the prefix-related information by diffusing the information selectively.[6] And each router in the network stores only the information of nearest copies rather than all copies in NLSR.

All aforementioned name-based routing approaches need all routers have global view of all prefixes. But there are numerous prefixes in the world and they are hard to be aggregated, the storage space and communication overhead is huge compared with legacy topology routing.

3. DPLSR PROTOCOL

Directed-Propagation Link-State Routing Protocol (DPLSR) is a link-state routing protocol which does not broadcast all messages anymore. Instead, messages of prefix-related information (or ALSA) are sent directionally to some dedicated nodes (or Root anchor). Thus it reduces communication overhead and storage space significantly. DPLSR can be applied to both hierarchical and flat network with multi-path routing. Before our description of DPLSR, we shall make some assumptions. All the messages traveling in the network are assumed to be disseminated correctly and each router has adequate storage capacity to store necessary information completely and correctly.

3.1 Anchor and LSA Message

In DPLSR, each router is distinguished by unique name. The router name also indicates its location, which is like URL in current IP-based network. Anchor is a special kind of router which stores a set of *Named-data Objects* (NDOs) permanently or semi-permanently. A (name) *prefix* represents a group of NDOs which can be accessed in the entirety. There are two types of anchors: *Root anchor* and *Replica anchor*. Root anchor of a prefix is the anchor which store all NDOs under the prefix permanently, while Replica anchor only cache the content for a limited duration. A prefix is binding to one and only one Root anchor, and the name of Root anchor is always attached to the prefix after the NDOs are published. Thus users are able to figure out the Root anchor once given a prefix.

Table 1: Contents of an LSA

Type	Content
RLSA	Router name, All the neighbors the link cost to each neighbor, Sequence Number
ALSA	Prefix,Root Anchor,Replica Anchor,isValid

Messages of Link State Advertisement (*LSA*) are also divided into two types: RLSA(*Router LSA*) and ALSA(*Anchor LSA*). The differences of them are illustrated in Table.1.

Same as it does in OSPF or LSCR[6], RLSA disseminates physical link states with broadcasting. Thus all nodes are aware of link states and network topology changes quickly. The communication and storage cost of this part is as same as OSPF and LSCR. For the sake of simplification, we don't compare the cost of this part in the rest of this paper.

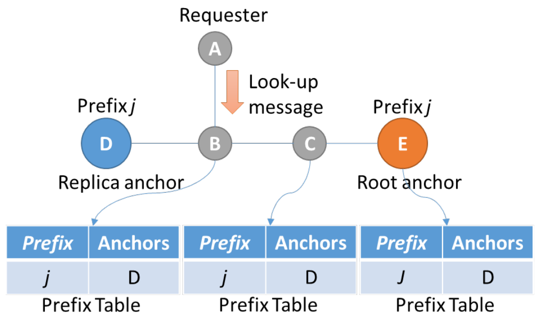
ALSA is to inform information about prefix and anchors. Since the amount of prefix is several order of magnitude of router number, the communication and storage overhead of ALSA has significant impacts on system performance. In DPLSR, ALSA is sent directly to Root anchor instead of broadcasting. Only nodes along the traverse path record the information of anchor and prefix. Root anchor has complete list of anchors related with this prefix.

3.2 Directed Propagation LSA

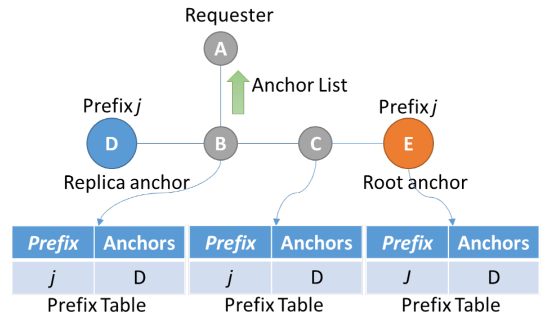
In DPLSR, only parts of nodes store prefix and anchor information. ALSA message is sent in a directed way. Thus the control message overhead and prefix storage are reduced significantly. Once users want to access to a content, an Look-up message is firstly send towards Root anchor binding with the according prefix. At the first node it encounters which records the anchor list of this prefix, the list will be returned to the users. Then they build data communication connections with these anchors. Hence multi-path transmission and nearest-copy routing is also supported by DPLSR.

The ALSA directed propagation phase is shown as in Figure.1. A Replica anchor which storing NDO-j published by others issues an ALSA messages with prefix-j. The name of prefix consists of four parts:

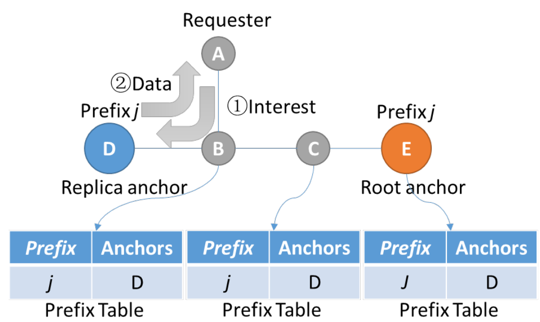
1. prefix name



(a) Look-up message sends towards Root anchor



(b) The first router it encounters returns the anchor list



(c) Nearest copy is downloaded from Replica anchor

Figure 2: Nearest-copy routing phase

2. router name of the Replica anchor that initiate it
3. router name of Root anchor
4. valid flag (isValid) that shows whether the prefix is valid in Replica Anchor.

According to Root anchor name carried by prefix, ALSA message are sent directly toward Root anchor hop-by-hop using legacy topology link-state routing protocol. Routers maintain a Prefix Table (PT) recording Prefix Anchor Set (PAS), which indicates names of the anchors that stores the NDOs associating with a prefix. Upon receiving ALSA messages, a router is supposed to check $isValid$ field to determine whether add or delete the Replica Anchor in PAS it maintains, and then forward ALSA message to the next hop towards Root anchor location.

3.3 Nearest-Copy Routing Protocol

there are two type of routing processes in DPLSR: (1)Legacy topology link-state routing (2)Prefix-based routing. The part of legacy topology link-state routing protocol is similar to the well-known link-state routing methods in IP networks. Upon receiving RLSA messages, every node builds a global topology map, called *Network Topology Table* (NTT), which contains: (1)all the routers in the network (2)all the links in the network and the cost of these links (3)the sequence number of received RLSAs. As nodes being be aware of whole topology of network, they are able to calculate shortest path to all routers using Dijkstra's algorithm.

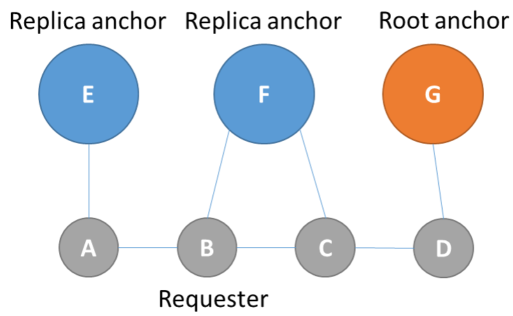
Prefix-based routing is a directed routing-by-name protocol, which consists of three steps as shown in Figure 2:

1. First, when a user requests NDOs with prefix-j, it sends an look-up message towards Root anchor binding in this prefix. This message includes the NDO's name and is delivered along the shortest path calculated by topology map the router builds.
2. Second, when a router receives the look-up message (including the router initiates this message), it looks up its PAS for prefix-j. If a anchor entry hits, router sends back an anchor list associated with the prefix to the original router. Meanwhile, look-up message forwarding is stopped. Otherwise, it will be forward to the next hop along the path to Root Anchor.
3. At last, users receive anchor list and choose one or more nearest anchors according to global topology link-state information. Then users are able to retrieve NDOs by building one or multiple connections with the Interest/Data model to download the wanted NDO.

3.4 Performance Analysis

We have compared the theoretic performance of DPLSR with other name-based routing protocols, focusing mainly on communication complexity (CC), storage complexity (SC), and NDO propagation delay (PD). CC is the number of LSA messages that make all routers have adequate information required to compute correct routing tables. SC is the amount of information that stores in each router to run the routing protocol correctly. PD is the needed time to download NDO which can be measured by hops or else.

Here we assume the number of routers and links in the network is denoted by N and E. C denotes the number of



(a) Network Topology

Router	Content of PAS for prefix j
A	E
B	E
C	E, F
D	E, F

(b) Content of PAS

Figure 3: As Router 2 initiates the Look-up message, it notices that PAS of prefix j on it is not empty and Replica Anchor 2 is nearest in PAS, so it downloads the data from Replica Anchor 2. However, Replica Anchor 1 is the nearest actually.

available prefixes in the network. The average number of the anchors for a given prefix is R, the network diameter is d, and the average number of neighbors per router is l.

Topology Link-State Routing (NLSR):

For each prefix, anchor initiates a prefix LSA and floods it. For physical link state, router initiates an adjacency RLSA consisting of link cost to all its neighbor and RLSA is flooded as well. Every router in the network stores the whole network topology and the information of all anchors and all prefixes. Routers can always download the Data packet through the shortest path from the nearest anchor. Accordingly, CC, SC, and PD are:

$$\begin{aligned} CC_{NLSR} &= O(ERC + lEN); \\ SC_{NLSR} &= O(E + RC); \\ PD_{NLSR} &= O(d); \end{aligned} \tag{1}$$

Distance-based Content Routing (DCR):

Each router in the network disseminates only one kind of messages informing the distance to each prefix by flooding, and only stores the next hop to each prefix. Routers can always download the Data packet through the shortest path from nearest anchor. Accordingly, CC, SC, and PD are:

$$\begin{aligned} CC_{DCR} &= O(EC); \\ SC_{DCR} &= O(C); \\ PD_{DCR} &= O(d); \end{aligned} \tag{2}$$

The lower CC and SC, however, make DCR unable to routing to all or some copies of a given prefix. To solve the problem, another approach named multi-instantiated destination spanning trees (MIDST)[5] is proposed.

Link State Content Routing (LSCR):

The messages it disseminates to have adequate information required to compute correct routing tables is similar to NLSR, but each router stores the information about the nearest anchor for each prefix rather than all the anchors together with the whole topology information of the network, which cut down the SC [3]. Apparently, Routers can always download the Data packet through the shortest path from the nearest anchor. Therefore, CC, SC, and PD are:

$$\begin{aligned} CC_{LSCR} &= O(ERC + lEN); \\ SC_{LSCR} &= O(E + C); \\ PD_{LSCR} &= O(d); \end{aligned} \tag{3}$$

Directed-Propagation Link-State Routing (DPLSR):

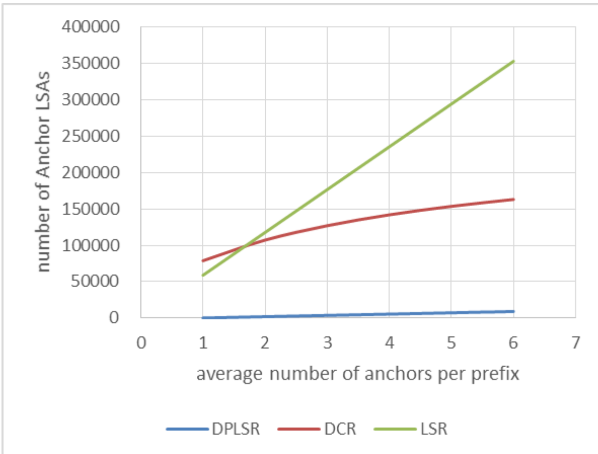
For each prefix, each anchor of it (except the Root Anchor) initiates an ALSA and ALSA propagates to the Root Anchor, which means the CC for each prefix is $O(dR)$. Each router in the network initiates a RLSA consisting of the link cost between all its neighbor and it which is flooded. Every router in the network stores the whole topology information of the network. For a given prefix, routers in the shortest path from Replica Anchor to Root Anchor stores the information about all the anchors of the prefix, according to which SC of all the routers in the network is $O(NE + dCR)$ and the average SC for each router is $O(E + \frac{dCR}{N})$. Requested data may be download from the other anchor rather than the nearest anchor, because for a given prefix, only the Root Anchor is aware of all the anchors and the anchor list returned by the ordinary router is likely to exclude the nearest anchor when this router is not in the path from nearest anchor to Root Anchor. Figure 3 shows a case that router fails to find nearest router.

However, PD will not exceed O(d), and CC, SC, PD are:

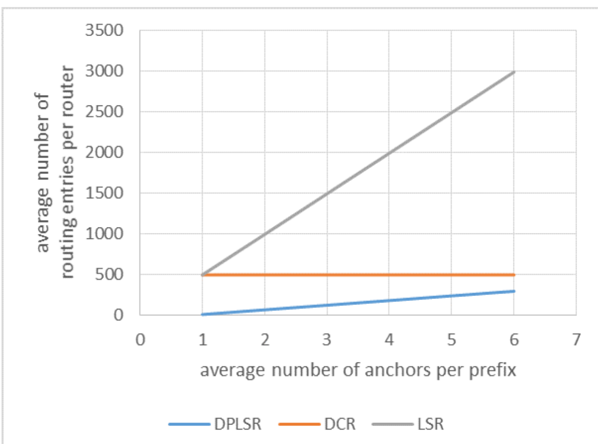
$$\begin{aligned} CC_{DPLSR} &= O(dRC + lEN); \\ SC_{DPLSR} &= O(E + \frac{CdR}{N}); \\ PD_{DPLSR} &= O(d); \end{aligned} \tag{4}$$

It is clear from Eqs.1 to 4 that DPLSR has a smaller CC and maintains the ability to routing to plural copies of a given prefix because in DPLSR information about prefix is no longer disseminated by broadcasting but is directional to the Root Anchor, which evidently cut down the communication overhead. As for SC, SC of DPLSR is apparently smaller than NLSR and likely to be smaller than LSCR when network topology is a dense graph, but there is a shortcoming that storage overhead of each router in the network does not keep a balance. Higher as PD of DPLSR is, PDs of the four approaches are in the same order of magnitude. In a non-hierarchical network, the PD loss of DPLSR compared to the other approaches can be up to $O(d)$ for each request in the worst case, but in a hierarchical network it will greatly decreases as the probability of the no-intersection case mentioned above is smaller.

4. EVALUATION



(a) Communication Cost



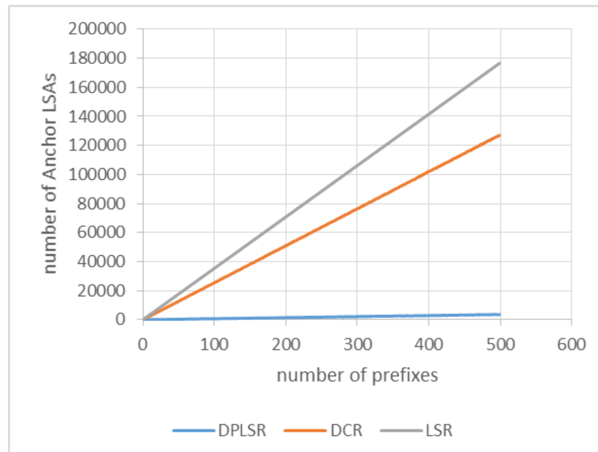
(b) Storage Cost

Figure 4: Performance of routing approaches with fixed number of prefix

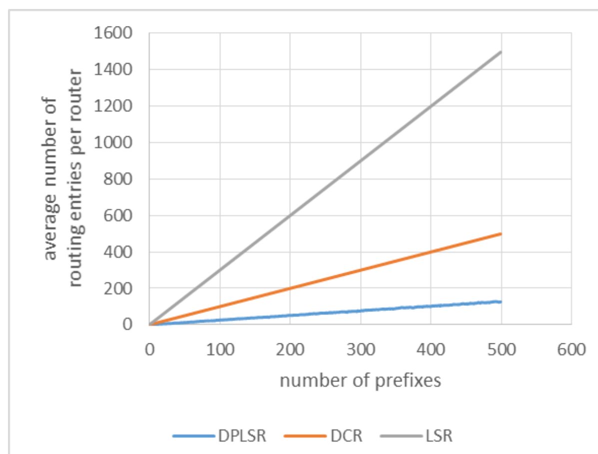
We compared DPLSR with LSR and DCR, using C++ to simulate the three approaches based on the simulated GEANT network[2], as done in [8] or [4]. It is a core network, composed by 40 routers and 59 links with a diameter of 8 hops, which interconnects several European research institutes and universities[9]. A node has 2.95 neighbors on average and there are 9 nodes with only one neighbor. Every links in the network is assigned a virtual cost.

LSR propagates LSAs(both adjacency and prefix LSAs) using flooding mechanism, while DCR propagates only the distance from a router to the nearest anchor of the prefix. Requests for prefixes is randomly occurs, and experiment done in each circumstance is repeated for 100 times in case of contingency. The performance metrics used to compare DPLSR with other name routing approaches is number of messages, average number of routing entries stored per router, and average hops for a request to get a given prefix.

Figure 4 shows the result when the average number of anchors per prefix increases from 1 to 6 and the number of prefixes is fixed to 499. Figure 4(a) shows that the number of ALSAs sent, which can be used to measure the communication cost of name routing approaches. DPLSR performs much better than LSR and DCR, which means directed-propagation is effective. Because in a network topology, the diameter of network is greatly smaller than number of nodes of the network. Storage cost is presented in Figure 4(b), measured by the average number of routing entries per router. When the average number of anchors per prefix increases, DCR and DPLSR, between which DPLSR costs lower to some extent, do better than LSR. DPLSR has a smaller storage mainly because only parts of routers stores the information regarding parts of anchors.



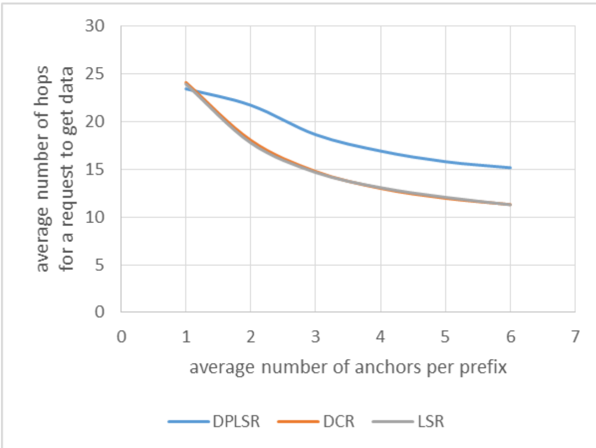
(a) Communication Cost



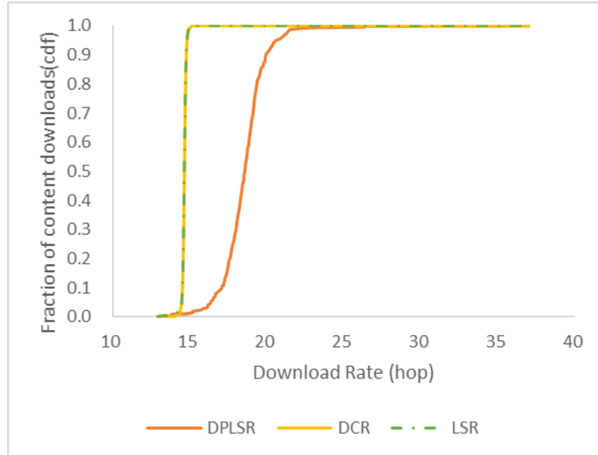
(b) Storage Cost

Figure 5: Performance of routing approaches with fixed number of anchors per prefix on average

Figure 5 shows the result when each prefix has 3 anchors on average and the number of prefixes shifts from 1 to 499. As the number of prefixes increase, it is foreseeable that communication cost and storage cost will increase according to our analysis in Section 3.4. From Figure 5(a) we can figure out that the communication cost of DPLSR increase



(a) download rate when number of prefixes fixed



(b) CDF of Download Rate when prefixes increase

Figure 6: Download rate

extremely slowly compared to DCR and LSR, which proves the merit of Directed Propagation again. In a real network there can be numerous prefixes, DPLSR takes great advantage in terms of communication overhead. Storage cost is presented in Figure 5(b). This is because not all the routers record information of prefixes and anchors as well.

Figure 6 shows the result in download rate measured by average link cost per request. Figure 6(a) presents the variation of download rate when the average number of anchors per prefix increases from 1 to 6 with fixed number of prefixes. Figure 6(b) is CDF of download rate when number of prefixes shifts from 1 to 499 with 3 anchors per prefix on average. Figure 6 indicates that download rate of DPLSR is lower than other two approaches expectedly. It is mainly because each prefix is only transferred to several routers, it cannot be guaranteed that every request could be routed to the nearest anchor. That causes the lost of download rate. But the download cost of DPLSR is less than twice of DCR and LSR while the communication and storage cost (especially communication cost) decrease by more than 2 times. We can figure out that weakness in download rate is acceptable compared with the advantages in storage space and communication costs.

5. CONCLUSION

The Directed-Propagation Link-State Routing (DPLSR) protocol is a name routing approach proposed for ICN architecture to deal with the issue of prefix flooding storm in NDN Link-state Routing Protocol. In DPLSR, routers storing NDOs are divided into two types: Replica anchor and Root anchor, according to the duration of stored prefixes. The significant mechanism for DPLSR to cut down communication overhead and prefix storage is called Directed Propagation, which is to forward prefix-related LSA messages only towards Root anchor rather than flooding as physical link-state information does. Look-up message is sent towards Root anchor to request an NDO. During this procedure, the first router receiving Look-up message with its Prefix Table hit returns the anchor list to the requester. Thus, NDO can be download from the nearest anchor in the returned anchor list. As simulated experiments verifies, DPLSR has reduced communication overhead and prefix storage with a tolerable loss in download rate. Meanwhile, it maintains the ability for users to access the nearest copy or build one or multi-path connections to the anchors. Although it avoids broadcasting storm effectively, more efforts should be made for DPLSR to get higher efficiency.

6. REFERENCES

[1] Content centric networking project (ccn). http://www.ccnx.org.

[2] Geant project website. http://www.geant.net/.

[3] Named data network project. http://www.named-data.net/.

[4] R. Chiocchetti, D. Rossi, G. Rossini, G. Carofiglio, and D. Perino. Exploit the known or explore the unknown?: hamlet-like doubts in icn. In *Proceedings of the second edition of the ICN workshop on Information-centric networking*, pages 7–12. ACM, 2012.

[5] J. J. Garcia-Luna-Aceves. Name-based content routing in information centric networks using distance information. In *Proceedings of the 1st international conference on Information-centric networking*, pages 7–16. ACM, 2014.

[6] E. Hemmati and J. Garcia-Luna-Aceves. A new approach to name-based link-state routing for information-centric networks. In *Proceedings of the 2nd International Conference on Information-Centric Networking*, pages 29–38. ACM, 2015.

[7] A. Hoque, S. O. Amin, A. Alyyan, B. Zhang, L. Zhang, and L. Wang. Nlsr: named-data link state routing protocol. In *Proceedings of the 3rd ACM SIGCOMM workshop on Information-centric networking*, pages 15–20. ACM, 2013.

[8] D. Rossi and G. Rossini. Caching performance of content centric networks under multi-path routing (and more). *Relatório técnico, Telecom ParisTech*, 2011.

[9] M. Tortelli, L. A. Grieco, and G. Boggia. Performance assessment of routing strategies in named data networking. In *IEEE ICNP*, 2013.