Information Centric Networking for Future Deep Space Networks

Yongqi Zhou(✉), Wenfeng Li, and Kanglian Zhao

Nanjing University, Nanjing, China
nju_zhou@foxmail.com

Abstract. With the flourish of the space sensing technology, various space information systems are playing an irreplaceable role in space exploration. Delay-Tolerant Networking (DTN) has been proposed to cope with the harsh transmission conditions and it provides a store-forward mechanism to push scientific data to Earth. However, in the future, Deep Space Networking (DSN) is bound to be more richer, while the volume of data transmission will rise considerably and communication services will also be diversified including both push-traffic and pull-traffic. In this way, we think DTN still needs to be improved while Content-Centric Networking (CCN) may be another candidate for these challenges. CCN [14] is a novel networking paradigm which has been used for terrestrial network and it provides both push-traffic and pull traffic for different scenes. Besides of it, cache mechanism can effectively reduce the influence arising from increase in data transmission. Therefore, we think CCN may be a better solution for future Deep Space Networking.

Keywords: Push-traffic · Pull-traffic · Cache · CCN

1 Introduction

Currently, the Deep Space Networking (DSN) has been researched extensively for scientific exploration. It provides a necessary communication system to receive commands from Earth to the spacecraft and to return scientific data. To date, Deep Space Networking (DSN) only consists of several relay orbiters and bound assets e.g., landers, rovers, probes, which presents a uncomplicated structure. Thus, deep space missions are traditional robotic missions [7] and scientific data collected by robot are directly pushed to Earth. Besides, DSN works in a harsh transmission conditions including long propagation delays, high loss of data, frequent link disruptions, dynamic changes of the network infrastructure, etc. In this way, Delay-Tolerant Networking (DTN) [15] has been proposed, which provides a store-forward mechanism in this environment.

DTN is a network architecture that supports significant delays or disruptions between data search and data receive phases. In this architecture, Bundle protocol (BP) plays a pretty significant role in which data units, termed bundles, can

M. Jia et al. (Eds.): WiSATS 2019, LNICST 280, pp. 437–448, 2019.
https://doi.org/10.1007/978-3-030-19153-5_45

be temporarily stored at intermediate nodes until an appropriate receiver can be found. Additionally, BP also provides custody transfer option to improve the reliability of transmission. When this function is opened, sender will not delete this bundle in local storage and resend it until receiving an acknowledgement from the next hop node. Therefore, DTN is useful for coping with disrupted links, long delays and intermittent connectivity. During this decade, DTN has been modified in many ways and it seems that DTN is pretty suitable for current Deep Space Networking.

However, with the flourish of the space sensing technology, more and more satellites and space probes will be put into operation for communication, broadcasting, Earth observation, navigation, and deep-space exploration, etc. More types of data including audio, video, new in-situ relay services for communications and navigation services will appear in the future DSN. What's more, interoperability and cross-support will be necessary to achieve the connectivity goals of the Mars Relay Network (MRN) in the human Mars era [10]. The communication connection fabric is bound to be richer: robotic sensors will push scientific data to Earth continuously while astronauts also need request some specific message from other nodes. Data transfer will no longer be limited to the single pathway between deep space and Earth, but all the entities will be interconnected and exchange data each other. Thus, future deep space network capabilities and services are based on a service oriented architecture and must be able to provide both push and pull transmission so that it can meet the diversified communication services. Additionally, it is necessary that the candidate architecture also have an effective measure to deal with the increase of data transmission. In this way, we think that DTN which is designed only for push traffic still need to be improved due to these predictable changes in future DSN.

Therefore, in this paper, we present an information-centric approach to meet aforementioned challenges. Information-Centric Networking (ICN) is a novel networking paradigm which is not based on the point-to-point scenario. Instead of the conventional host-centric, content is considered to be the first element in ICN and each of them has a unique name as the identifier. Several ICN architecture proposals have emerged from research communities and Content-Centric Networking (CCN) is one of these proposals. In CCN, each node has three important data structure, namely the content store (CS), the pending interest table (PIT) and the forwarding information base (FIB) [5]. CS caches data transmitted through it. When some interest is coming, PIT records its incoming interface. Then, the table is checked when the content message returns to forward it. FIB is just like the IP routing table. It forwards the incoming interest message by names prefix. The CCN paradigm is the ideal candidate architecture for the implementation of that space internetworking.

Generally, there are several benefits that CCN could provide.

1.1 In-network Storage

In CCN, all hosts have CS. When receiving some content message, they decide whether to cache the content message according to the corresponding mechanism. In this way, many hosts have the duplicate, and thus, when consumer requests the same content, the interest message will be responded quickly. Therefore, it reduces both of distance and latency in transmission and improves the quality of service [9,12]. It is worth mentioning that in space networking, power constraint is a prominent problem and communications consume more power than other activities, so cache mechanism also contributes to saving devices power partly.

1.2 Data-Centric Security

CCN provides a security mechanism based on the message, which is totally different from the host-based mechanism in IP [6]. Three entities are included in it and interrelated with each other, as shown in Fig. 1. Real World Identity (RWI) means real identity of satellites or space probes in the space and Name represents content name. Then producer associates a public key with a private key. When receiving a content message, consumer verifies whether the producer does publish this content. This mechanism is directly built on message to ensure the reliability of the content source.

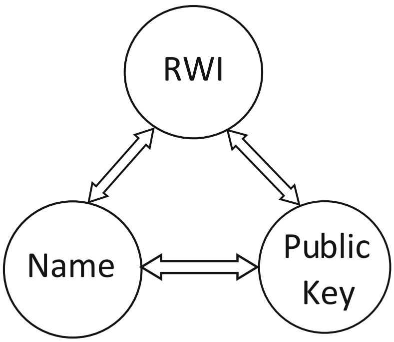

Fig. 1. Entities in security mechanism.

1.3 Handing Mobility

CCN supports mobility inherently [4]. When a consumer moved for a long distance, it can resend the unsatisfied interest message and wait for the respond. Besides, consumer can use different interfaces to forward or send message due to the native support of host multi-homing. It is complex when producer moves because FIB of neighbor nodes need to be updated slowly, which brings latency. However, thanks to its in-networking and multi-homing, the influence of producer mobility is weakened to some degree.

Besides of these, we identity four primary points of common characteristics between CCN and DTN [16]:

– Network Storage: Both architectures rely on in-network storage.
– Late Binding: Both approaches espouse the late binding of names to locations.
– Data Longevity: Both approaches make the units of network interaction (ICN data objects, DTN bundles) into long-term entities in comparison to traditional IP packets.
– Flexible Routing: Both approaches relax traditional constraints on routing and transport (loop free, multi-homing), making richer routing substrates possible.

These similar capabilities or elements seem to indicate that CCN, like DTN, can also be an alternative solution for DSN, and we will compare these two architectures in different scenarios as follows.

2 Comparisons Between CCN and DTN for Future DSN

In [8], Kevin Fall has made a comparison between Information Centric and Delay Tolerant Networking as shown in Table 1.

Table 1. Comparison between ICN and DTN

Feature	DTN	ICN
Push model	Yes	No but “preplacing” content - similar
Interest	Recent	Yes
Storage	Persistent	Transient (persistent is add-on)
Custodian	Integral	Separate
Node IDs	Yes	Varies [No (NDN)/Yes (Netinf)]
Conv.Layer	Yes	Yes (Netinf - explicit)/Yes (CCN - effectively)
Lifetimes	Yes	Yes (on data and on interests)
Names	Regex on strings (URI)	Prefix-based names (CCN); flat names (Netinf)

We can see that many specifics have been mentioned in this table. Firstly, DTN names endpoints, groups or predicates with URI-based format while ICN names data and matches data to interest. Secondly, DTN uses storage to primarily for persistence and disruption tolerance, but storage in ICN mainly acts as a cache. Security models are also different because DTN provides security of channels and ICN pays more attention to content security. Besides of these, to make more distinct comparisons between CCN and DTN in deep space environment, we analyse these two architectures in future Mars-Earth system, as illustrated in Fig. 2.

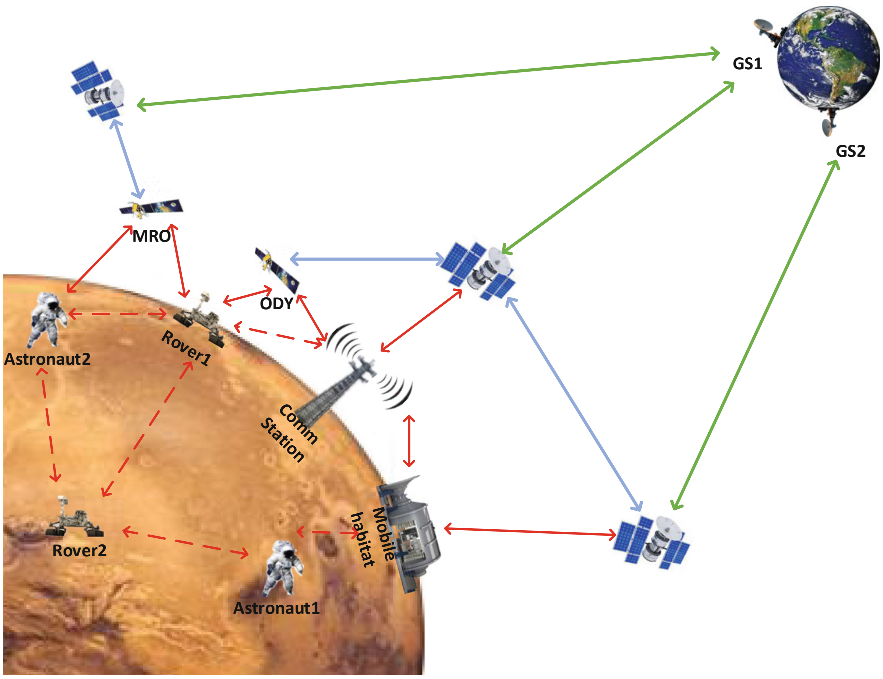

Fig. 2. Connectivity in future DSN.

2.1 Push-Traffic

Forwarding data to Earth without being requested (Push-traffic) is the basic mission in deep space exploration and DTN is just designed for this scene. We simplify the Mars-Earth system as shown in Fig. 3 and assume that node-A need to push data to node-B. Then, this mission is divided into two processes: data transmission and reply of ACK as shown in Fig. 3.

Correspondingly, CCN also provides a mechanism to support push-traffic: Long-Lived Interest [3,13] depicted in Fig. 4. In the beginning, consumer sends a long-live interest message to producer. Different from standard interest message, it has a very long lifetime. Producer receives such request and waits for the generation of corresponding content. Once the corresponding sensors collect a set of information, they push matched content to respond the request. Then, the lifetime is refreshed to wait for the next periodic content. So, the long-lived interest maintains a state of waiting for being responded in producers. Due to the high loss of data in transmission, if consumer fails to receive the content within vRTO (equal to lifetime), it resends this long-lived Interest. vRTO is a little larger than the interval between data generation. During this process, pull-based transmission is normally running. In this way, we omit the process of requests transmission and achieve the push-traffic of periodic data.

Therefore, in terms of push-traffic, both CCN and DTN perform well.

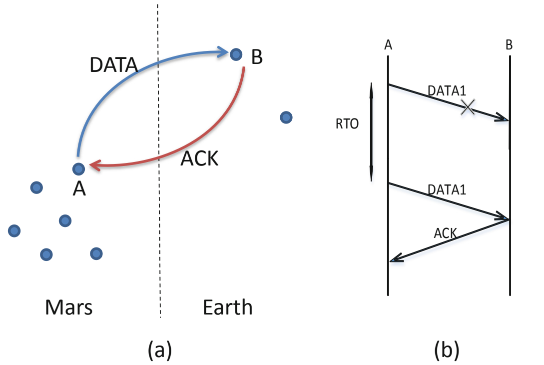

Fig. 3. Push-traffic in DTN.

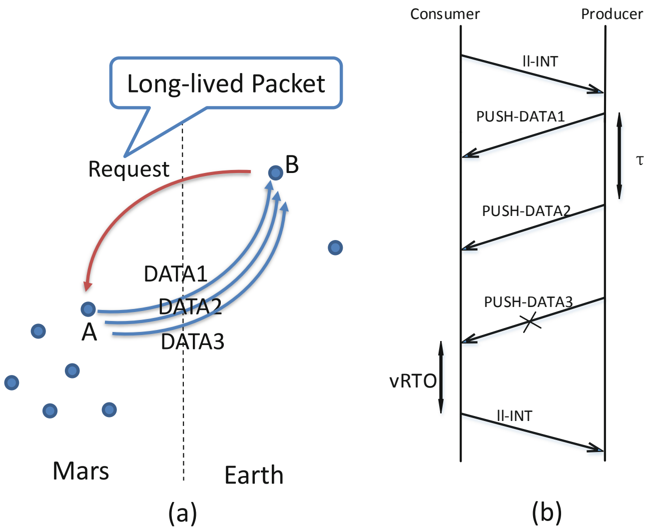

Fig. 4. Push-traffic in CCN.

2.2 Pull-Traffic

Due to the increase of nodes and human activities in DSN, communication services wouldn't be limited to push-traffic any more. Sometimes, we also need to request some specific data that we urgently need. In this way, request-respond transmission (Pull traffic) is necessary while DTN didn't take this scenario into consideration. So it is complicated to finish this process as depicted in Fig. 5. Firstly, nodeA will forwards a message containing its request to the network. After receiving it, nodeB responds an ACK and then sends the corresponding data to nodeA. Finally, nodeA gets the data it needs and sends an ACK to complete this request-respond transmission. From these processes, we can see that it is really complicated to implement this function in DTN while it also consumes more resources and time.

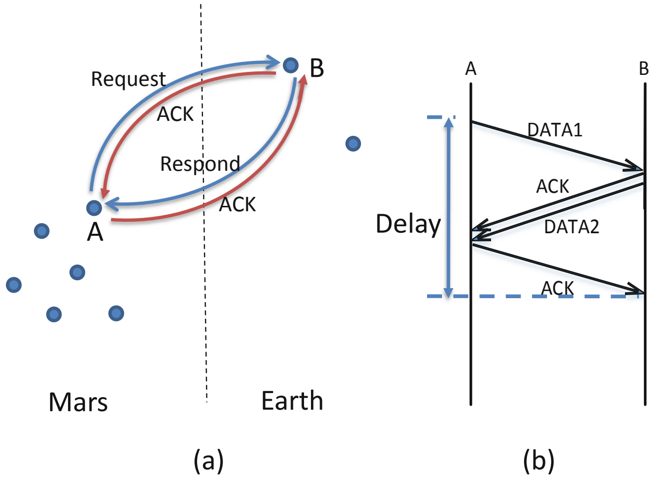

Fig. 5. Pull-traffic in DTN.

However, CCN provides pull-traffic inherently. In Fig. 6, nodeA just forwards an interest package to the network and any node could respond if they have these content in their local content store. These processes are pretty simple and multi-homing can effectively reduce the transmission latency. So, we can see that in the scenario of pull-traffic, CCN has a better performance than DTN does.

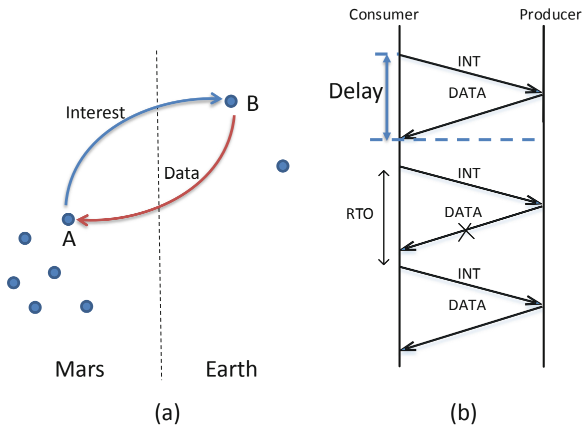

Fig. 6. Pull-traffic in CCN.

2.3 Cache

As mentioned in Sect. 1, some nodes in DSN may have content store to cache important data, such as communication station, mobile habitat, etc. In Fig. 7, node1 and node7 completed a data transmission and in this process, node6 cached this message. After that, another request of this data can be responded directly by node6. In this way, part of the requested data may be directly responded by nodes on Martian surface. Through this mechanism, we can avoid the transmission in inter-satellite links and reduce the latency, while DTN don't provide this function.

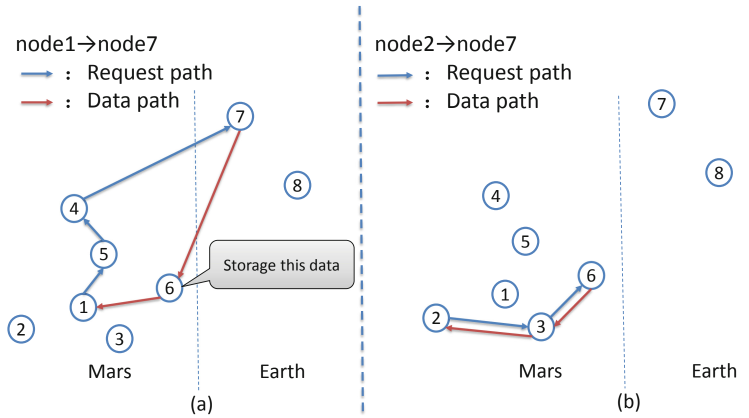

Fig. 7. Cache in CCN.

Through these comparisons, we come to the preliminary conclusion that CCN can basically realize the function of DTN, namely push-traffic. What's more, CCN also provide request-respond mechanism conveniently to support diversified communication services in the future.

3 Implementation

In this section, we apply CCN to Mars-Earth system to verify the implementation of push traffic, which is the basic mission in scientific exploration. Besides of it, we achieve the transmission mode of request-respond in another experiment.

To this end, we implemented modified CCN simulator in OPNET [11], which includes data structures of content store (CS) with caching mechanism, pending interest table (PIT), forwarding information base (FIB), contact graph routing (CGR), push-traffic by long-lived interest and so on. Then we build this scenario as shown in Fig. 8 to evaluate the performance of CCN. There are six nodes in this scenario with two astronauts (EVA1, EVA2), two grand stations (GS1, GS2) and two relay orbiters (MRO, ODY) [1].

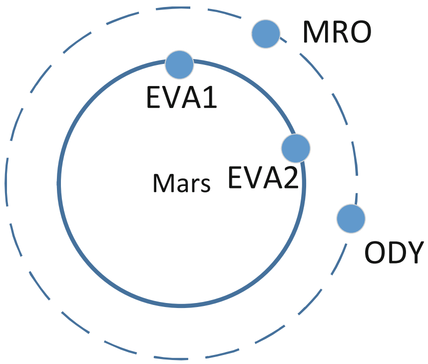

Fig. 8. Experimental scene.

Figure 9 depicts the contact plan exported from STK. The horizontal axis shows the time divided into equal one hour intervals and the vertical axis represents the moment that two nodes are in contact with each other [2]. Simulation parameters are set as represented in Table 2.

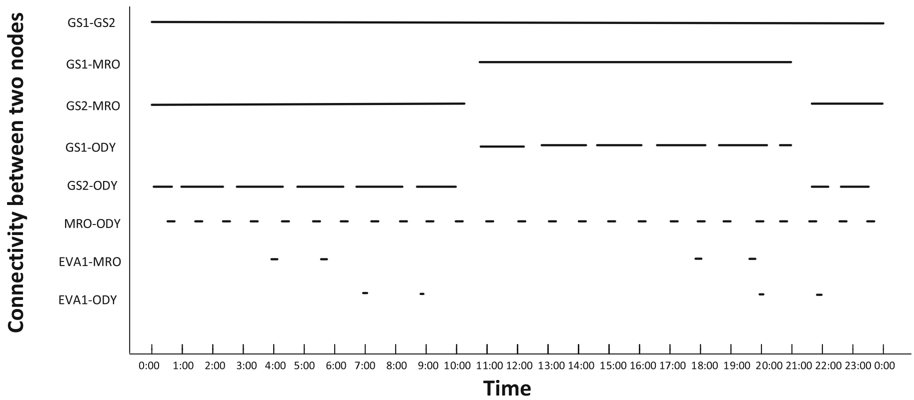

Fig. 9. Contact plan.

3.1 Push

In this scenario, we expect that EVA1 will forward scientific data to GS1 continuously without being requested. Then, GS1 firstly send a long-lived interest to EVA1 and this interest will be stored in EVA1 forever even if it once responded to it.

In Fig. 9, we can see that from 4 o'clock, EVA1 generate corresponding message every one hour and send it to GS1. As the link between EVA1 and satellite

Table 2. Simulation parameters

Scenario type	CCN
Link Data Rate (EVA-Satellite) (Mbps)	100
Link Data Rate (Satellite-Ground Station) (Mbps)	10
Latency (EVA-Satellite) (sec)	0.012
Latency (Satellite-Ground Station) (sec)	750
Interest Packet Size (byte)	80
Data Packet Size (Mbyte)	5
Interest Packet Inter-arrival time (sec)	Constants (3600)
Data Packet Inter-arrival time (sec)	Constants (3600)
Length of Simulation Run (sec)	86400

is frequently disrupted between 4 o'clock and 9 o'clock, transmission delay in this interim would be unstable but in a small range. After 9 o'clock, EVA1 can connect with neither MRO nor ODY until 18 o'clock. Thus, there will be a huge latency over nine hours when transmissions start during this period. Figure 10 shows the simulation result that accord with the above description.

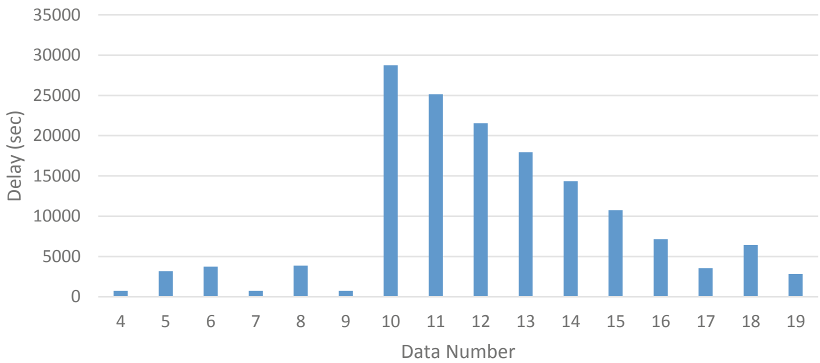

Fig. 10. Push-traffic

It is worth to mention that the path will be recalculated every time before EVA1 replies, instead of following the record in PIT according to the original CCN. In this way, we realize the push-traffic in CCN which is similar with DTN.

3.2 Pull

In this experiment, EVA1 requests data storing in GS1 every hour and waits for the corresponding data. If EVA1 receives a packet that has been requested,

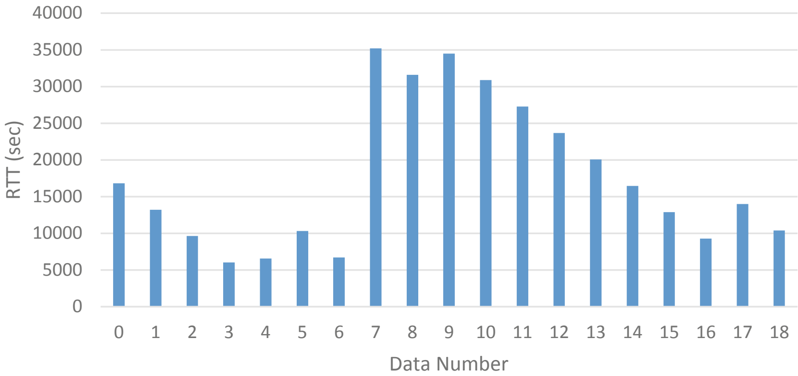

Fig. 11. Pull-traffic

it will record the time of forwarding and receiving. After seven thousands seconds of simulation, we stop this pull-traffic and print the transmission record as illustrated in Fig. 11.

To verify the correctness of these result, we can focus on the relevance of Figs. 9 and 11. In the beginning, requests before 4 o'clock would be stored in cache until the connection between Mars and relay orbiter is established. So, the latency before 4 o'clock presents a downtrend due to the different start time of requests. After 7 o'clock, although we can send request packet by a short-time link between EVA and ODY, data return would still be put back because the corresponding paths are unavailable until 18 o'clock.

4 Conclusion and Future Work

Currently, Delay-Tolerant Networking provides a store-forward mechanism to support push-traffic of scientific data in DSN. However, due to the increase of data transmission and diversification of communication services, we think CCN may be a candidate solution for these challenges, while it inherently provides both of pull-traffic and push-traffic. Further, cache can help to reduce the effects caused by the increased data transmission.

Therefore, in this paper, we implement modified CCN in OPNET including three data structures, contact graph routing, push-traffic, pull-traffic and so on. Then we apply it to Mars-Earth system to preliminarily evaluate the performance in DSN. Finally, we realized our idea in this scenario.

However, in this paper, we only preliminarily verified the feasibility of applying CCN to future DSN. Some aspects still remain to be researched. For example, cache can effectively reduce the transmission latency, but almost all the nodes in DSN don't have enough space to store these content. Our future work will be devoted to the verification of cache mechanism.

References

1. Alaoui, S.E., Palusa, S., Ramamurthy, B.: The interplanetary internet implemented on the geni testbed. In: 2015 IEEE Global Communications Conference (GLOBECOM), pp. 1–6, December 2015. https://doi.org/10.1109/GLOCOM.2015.7417313
2. El Alaoui, S.: Routing optimization in interplanetary networks (2015)
3. Amadeo, M., Campolo, C., Molinaro, A.: Internet of Things via named data networking: the support of push traffic. In: 2014 International Conference and Workshop on the Network of the Future (NOF), pp. 1–5, December 2014. https://doi.org/10.1109/NOF.2014.7119766
4. Amadeo, M., et al.: Information-centric networking for the Internet of Things: challenges and opportunities. IEEE Netw. **30**(2), 92–100 (2016). https://doi.org/10.1109/MNET.2016.7437030
5. Amadeo, M., Campolo, C., Molinaro, A.: Information-centric networking for connected vehicles: a survey and future perspectives. IEEE Commun. Mag. **54**(2), 98–104 (2016)
6. Baccelli, E., Mehlis, C., Hahm, O., Schmidt, T.C.: Information centric networking in the IoT: experiments with NDN in the wild, pp. 77–86 (2014)
7. Cola, T.D., Paolini, E., Liva, G., Calzolari, G.P.: Reliability options for data communications in the future deep-space missions. Proc. IEEE **99**(11), 2056–2074 (2011)
8. Fall, K.: Comparing information-centric and delay-tolerant networking. In: IEEE Conference on Local Computer Networks, p. xxxiii (2012)
9. Fall, K.: A message-switched architecture for challenged internets, October 2018
10. Kazz, G., Burleigh, S.C., Cheung, K.M., Shah, B.: Evolution of the mars relay network end-to-end information system in the mars human era (2030–2040). In: International Conference on Space Operations (2016)
11. Kim, S., Kim, K., Choi, S., Kim, B., Roh, B.H.: An implementation of content-centric network, using OPNET modeler. In: Opnetwork (2012)
12. Lindgren, A., Abdesslem, F.B., Ahlgren, B., Schelén, O., Malik, A.M.: Design choices for the IoT in information-centric networks. In: 2016 13th IEEE Annual Consumer Communications Networking Conference (CCNC), pp. 882–888, January 2016. https://doi.org/10.1109/CCNC.2016.7444905
13. Majeed, M.F., Ahmed, S.H., Dailey, M.N.: Enabling push-based critical data forwarding in vehicular named data networks. IEEE Commun. Lett. **21**(4), 873–876 (2017). https://doi.org/10.1109/LCOMM.2016.2642194
14. Rubenstein, D., Misra, V., Feng, H., Martin, M.C.: Content centric networking (2014)
15. Torgerson, L., et al.: Delay-tolerant networking architecture. RFC 4838 (2007). https://doi.org/10.17487/RFC4838
16. Tyson, G., Bigham, J., Bodanese, E.: Towards an information-centric delay-tolerant network. In: 2013 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), pp. 387–392, April 2013. https://doi.org/10.1109/INFCOMW.2013.6970723