Enhanced IoT Data Acquisition in Information Centric Networks

Lijun Dong(✉)

Futurewei Technologies Inc., 10180 Telesis Court, Suite 220,
San Diego, CA 92121, USA
lijun.dong@huawei.com

Abstract. The new characteristics of IoT (Internet of Things) data and clients' IoT data retrieval require the ICN infrastructure to be more intelligent and advanced capabilities. This paper proposes enhanced in-network functionalities of ICN routers, which are smart in-network caching, context-aware forwarding. The paper illustrates the proposed enhanced in-network capabilities of ICN routers to enable the efficient IoT data acquisition. The simulation shows the significant performance improvement with different network settings.

Keywords: Information centric networks · In-network capabilities
Internet of Things · Data acquisition

1 Introduction

Information-Centric Networking (ICN) [1] has emerged as a promising candidate for the architecture of the future Internet as well as the future Internet of Things (IoT) [2]. ICN integrates name-based routing and in-network caching as fundamentals of the network infrastructure. The NDN architecture [4] is one of the most influential ICN architectures in the community. A NDN router maintains three data structures: the Forwarding Information Base (FIB) that associates the content names to the forwarding face(s) towards the producer(s), the Pending Interest Table (PIT) that records the incoming faces where the interests came from and have not replied by producer, the Content Store (CS) that caches content from a producer when it is forwarded to the requesters.

IoT Data [5] has some unique characteristics. One of them is that IoT data is normally measured in time series, thus associated with time context information. Both historic and fresh data may be needed by the client. On the other hand, IoT data may vary greatly in sizes and is normally associated with the location context information.

In general, IoT data may be associate different kinds of context information. Context [3] is defined as any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.

Clients' IoT data acquisition usually requires that the data satisfies certain conditions on associated context information, such as time, size and location requirements.

M. Huang et al. (Eds.): WICON 2016, LNICST 214, pp. 272–278, 2018.
https://doi.org/10.1007/978-3-319-72998-5_28

A typical client's request would look like: I want the traffic video at time 3:30 PM today on route 56 exit 3; I want the temperature of today in 92121.

Currently, the NDN routers only provide the basic functions of in-network caching, name based message forwarding. The NDN routers lack the context-awareness capability for data acquisition. Due to unawareness of the context information, a NDN router may not be able to make the correct decisions on choosing the forwarding face if there are multiple producers for the requested data. The network bandwidth could be wasted on the message or data transmission that is not needed by the client. Therefore, it is extremely important to enable enhanced context-awareness capability for content acquisition by NDN primitives and protocols. This paper proposes the new capability of context aware forwarding and smart in-network caching for the NDN routers.

2 Enhanced IoT Data Acquisition

The paper proposes that the enhanced in-network capabilities can be incorporated into the NDN routers.

- Smart In-Network Caching: a NDN router can cache the information that is forwarded by itself. It is proposed that the information could be in different kinds of categories, such as an interest message for data retrieval and subscription, semantics information of a resource, data discovery result, etc., other than just named content/data resource. The caching criteria could be different for different categories of information. Each NDN router can make independent decisions or collaborate with neighboring routers on deciding whether to cache the information being routed through.
- Context Aware Forwarding: a NDN router can forward a content acquisition request based on the specified context requirements. The context information may also be piggybacked in data message and recorded by the NDN router when the data message is being forwarded. As a result, the context information is associated with the IoT data stored in the CS, the forwarding entries maintained in the FIB, as well as the pending interests in the PIT. When an interest is received by a NDN router, it needs to match not just the content name in the request, but also the context requirement incorporated in the interest message. If it finds an exact match of the data in the CS with the same name and the same context information, then the data is returned to the client. Otherwise, the interest is either added in the PIT along with the context requirement, or aggregated in the existing entry in the PIT with the same requested data name. If the interest is totally new to the PIT (a new entry is added in the PIT), then the interest message is forwarded to the other NDN router based on the FIB. The context aware forwarding capability enabled in the FIB will try to match the contextual requirement in the interest message with the context associated the forwarding faces for the same requested data name. The most matched face is used to forward the interest message to the next NDN router until it reaches a producer that can provide the IoT data.

In the following, we use the examples shown in Fig. 1 to illustrate how context-aware content acquisition is supported in the ICN networks (e.g. by NDN routers).

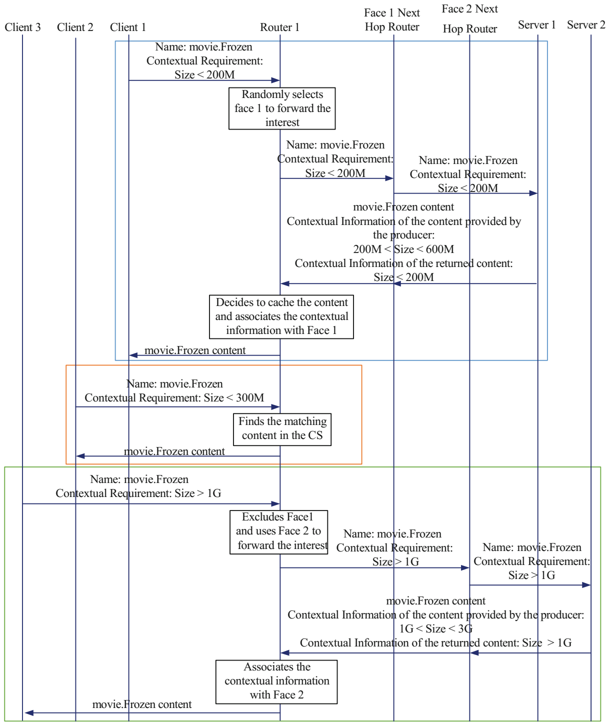

Fig. 1. Exemplary message flow of context-aware content requests

The client 1 sends an interest with the content name (i.e. movie.Frozen) and contextual requirement (i.e. Size < 200 M) to the attached router 1. The FIB for the prefix movie.Frozen exists in the router 1, which has two forwarding faces, i.e. 1 and 2. The forwarding faces are not associated with any context information yet. The router 1 can randomly selects one of the faces to forward the interest to limit the overhead in propagating the interest message. In the example, the face 1 is chosen. The face 1 next hop router then forwards the interest to one of the producers, i.e. the server 1. The server 1 processes the interest request, extracts the content name and the contextual requirement. The server 1 finds that it can provide the content data with matching contextual information. The server 1 replies with the content data, and piggybacks the contextual information of the content that can be provided by itself (i.e. 200 M < Size < 600 M, which indicates all the sizes that the Server 1 is able to provide for the content movie.Frozen), as well as the original contextual requirement of the returned content (i.e. Size < 200 M). The content is forwarded via the reverse path to the router 1. The router 1 returns the content to the client 1. The router 1 decides to cache the content based on the local caching criteria. The cached content has contextual information of “Size < 200 M”. The router 1 associates the piggybacked contextual information to the forwarding face 1. It indicates that through the face 1, the content movie.Frozen with the contextual information of “200 M < Size < 600 M” can be returned.

The client 2 sends an interest with the content name (i.e. movie.Frozen) and contextual requirement (i.e. Size < 300 M) to the attached router 1. The router 1 finds a local cached copy which satisfies the contextual requirement, and returns to the client 2. The interest is dropped at the router 1.

The client 3 sends an interest with the content name (i.e. movie.Frozen) and contextual requirement (i.e. Size > 1G) to the attached router 1. The router 1 is able to exclude the face 1 since its associated contextual information opposes to the required one. The router 1 is contextual aware in making the decision to forward the interest to the face 2. The face 2 next hop router then forwards the interest to one of the producers, i.e. the server 2. The server 2 processes the interest request, extracts the content name and the contextual requirement. The server 2 finds that it can provide the content data with matching contextual information. The server 2 replies with the content data, and piggybacks the contextual information of the content that can be provided by itself (i.e. 1G < Size < 3G, which indicates all the sizes that the Server 2 is able to provide for the content movie.Frozen), as well as the original contextual requirement of the returned content (i.e. Size > 1G).

The content is forwarded via the reverse path to the router 1. The router 1 returns the content to the client 2. The router 1 decides not to cache the content due to limited storage. The router 1 associates the piggybacked contextual information to the forwarding face 2. It indicates that through the face 2, the content movie.Frozen with the contextual information of “1G < Size < 3G” can be returned.

3 Performance Evaluation

In this section, we evaluate the performance of the mechanisms proposed in the previous sections. The event-driven simulator simulates and compares the proposed context-aware solution versus the random selection and round-robin selection of forwarding faces for content request with contextual requirement. In the random selection approach, each ICN router receiving an interest always randomly selects a forwarding face in the FIB corresponding to the requested content name, if there are multiple ones. In the round robin approach, each ICN router receiving an interest always forwards it to the faces in a round-robin manner.

The metric evaluated is “success rate per sent interest”, which quantifies the average successful ratio for the client receiving the content which satisfies the contextual requirements, among all interest messages sent during the simulation.

In the first set of simulations, we vary the network connectivity, which is defined as the probability that two nodes in the network connecting to each other. The total number of nodes in the network is 180. The total number of interests in the workload is 10000. The total number of content in the network is 1000. The maximum number of contexts per content is 5.

Figure 2 includes two figures on the success ratio per sent interest with network connectivity varies from 0.2 to 0.6: (a) Without retransmission. The option adopted is that after an interest fails, the interest is dropped by the client without retransmission. For random selection and round robin mechanisms, the success ratios are similar, which are around 60%. It indicates that when an ICN router chooses a forwarding face from multiple faces either randomly or in a round-robin manner, it can't guarantee that the interest reaches the accurate content provider satisfying the contextual requirements. However, with proposed context-aware solution, with contextual information associated and recorded in the FIB, the ICN router can make the right decision in choosing the forwarding face towards the accurate content provider. After the FIBs in ICN routers are stable, the success ratio per sent interest of the proposed context-aware solution can stay as 100%. (b) With retransmission to ensure successful content retrieval. The option adopted is that after an interest fails, the interest is resent by the client until it reaches the maximum retry number. The maximum retry number is set to be large enough to ensure that every interest would be eventually replied with a content satisfying the contextual requirements. With the number of successful interests to be fixed (i.e. the number of the interests in the workload), the success ratio per sent interest performance in Fig. 2(b) indicates that the round robin mechanism has better chance over the random selection mechanism to reach the accurate content provider with retransmission. When the network connectivity increases, the number of hops between two nodes in the network (i.e. between the client and the content provider) is smaller, while the number of forwarding faces for a content in an ICN router may be larger. Those two factors result in the success ratio per sent interest to be constant when network connectivity varies in both option (a) and (b).

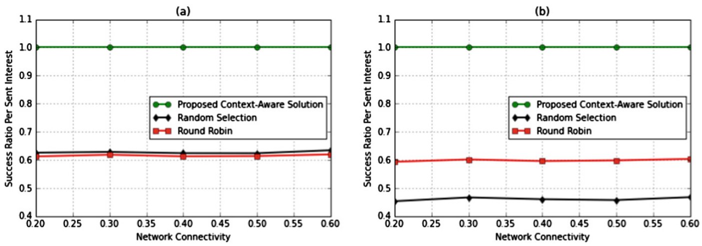

Fig. 2. Success ratio per sent interest vs. network connectivity

In the second set of simulations, we vary the parameter of context variety per content, which is defined as the maximum number of associated contexts for each-content. The number of associated contexts for each content is set up randomly between 1 to this parameter. We assume that there is one and only one content server to provide a content with one context, which suggests that the number of content provider for each content is same as the number of the content's associated contexts. The total number of nodes in the network is 180. The network connectivity is 0.3. The total number of interests in the workload is 10000. The total number of content in the network is 1000.

Figure 3 includes two figures on the success ratio per sent interest with context variety per content changes from 2 to 8: (a) Without retransmission. The random selection and round robin mechanisms show almost the same performance in success ratio per sent interest. When the context variety per content increases, the success ration per sent interest for both mechanisms decreases from 100% to 55%, while the proposed context aware solution maintains the 100% successful ratio per sent interest when the FIBs in ICN routers are stable. (b) With retransmission to ensure successful content retrieval. The round robin mechanism performs slightly better than random selection mechanism, but both still follow the same performance decreasing trend with the increment of the context variety per content. The proposed context aware solution again maintains 100% success ratio per sent interest, which means every request in the workload is satisfied with the accurate content after every single interest message is sent out.

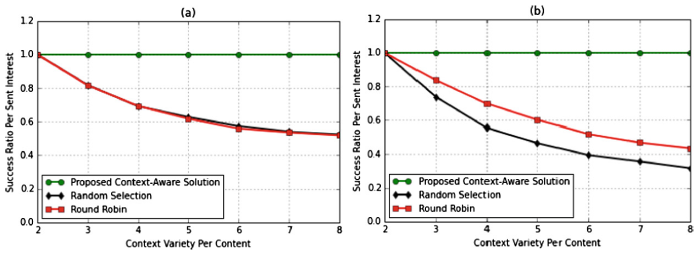

Fig. 3. Success ratio per sent interest vs. context variety per content

4 Conclusion

In IoT applications/use cases, the content acquisition requests from clients often involve the contextual requirements. Only such contextual requirements are satisfied by the returned content, the content retrieval request can be considered successful. In the paper, we proposed the enhanced in-network capabilities to support IoT data acquisition in the ICN infrastructure. We performed thorough simulations to evaluate the performance of the proposed context-aware solution compared to the two existing mechanisms: random selection and round robin. The results verified the substantial performance improvement of the proposed solution with very little network overhead.

References

1. Xylomenos, G., Ververidis, C.N., Siris, V.A., Fotiou, N., Tsilopoulos, C., Vasilakos, X., Katsaros, K.V., Polyzos, G.C.: A survey of information-centric networking research. IEEE Commun. Surv. Tutor. **16**(2), 1024–1049 (2014)
2. Baccelli, E., Mehlis, C., Hahm, O., Schmidt, T., Wahlisch, M.: Information centric networking in the IoT: experiments with NDN in the wild. In: ACM ICN (2014)

3. NDN: The Named Data Networking Project. http://www.named-data.net/
4. Dey, A.K.: Understanding and using context. Pers. Ubiquit. Comput. J. **5**, 4–7 (2001)
5. Zhang, Y., Raychadhuri, D., Grieco, L., Baccelli, E., Burke, J., Ravindran, R., Wang, G., Lindren, A., Ahlgren, B., Schelen, O.: Requirements and challenges for IoT over ICN. https://datatracker.ietf.org/doc/draft-zhang-icnrg-icniot-requirements/