A Robust and Lightweight Name Resolution Approach for IoT Data in ICN

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***Abstract*—One discriminating characteristics of data in the Internet of Things (IoT) applications is that it may have multiple producers (e.g. many sensor devices deployed in an area to sense the same information). It is very important that the name resolution service is able to provide the proper producer selection based on client's criteria and the producers' contextual information. The paper proposes a robust and lightweight name resolution approach for IoT data in Information Centric Networking, which is considered to be one of the most promising architectures for future Internet as well as future IoT. The paper considers that each content has a Home Node, which acts as the only host virtually to the rest of the network. The paper discusses the procedures for Home Node adjustment due to the appearance of a new producer or disappearance of an existing producer. It also presents the solution for Home Node recovery when failure happens. The paper analyzes the advantages of the proposed approach, such as significantly less update message overhead, efficient storage usage and resilience to node failure.**

Keywords—Distributed; name resolution; Information Centric Networks; Internet of Things; node failure; node recovery

I. INTRODUCTION

In ICN (Information Centric Networking) design, a name is used to identify an entity, such as a named data content, a device, an application or a service. ICN requires uniqueness and persistency of the name of any entity to ensure the reachability of the entity within certain scope and with proper authentication and trust guarantees. The Name Resolution Service (NRS) is defined as the service that is provided by ICN infrastructure to help a client to reach a specific piece of content, service, or host using a persistent name. The NRS could take the standalone name resolution approach (SNR) to return the client with the locators of the content, which will be used by the underlying network as the identifier to route the client's request to one of the producers. The examples are iDNS [1], Global Name Resolution Service (GNRS) [2], and Locator/ID Separation Protocol (LISP) based approach [3][4]. The NRS could take the name based routing approach (NBR) such as in NDN [7], which integrates the name resolution with the content request message routing. No matter which approach is taken by the NRS in ICN, it is the most essential component or service of the ICN infrastructure.

A content could have multiple producers, especially in the IoT applications. Such IoT applications have many sensor devices of the same type deployed in one location to provide the sensing data. Thus the multiple producers for the same content information are very likely to be located in the same neighborhood of the network. A new requirement arises to be satisfied by the NRS, which should be able to return all the active producers for the client's selection or select the best producer based on the client's criteria and contextual information.

The SNR approach requires the producers' context information such as load, bandwidth, response time, location, etc. to be registered with the NRS overlay server in the local domain and propagated/notified in the entire NRS overlay. However, the NRS overlay server may need to manage a large amount of information about all the content in the local domain, which requires comparatively long processing time and a lot of resource capability (CPU, storage etc.). And it can also easily become the single point failure and security attack target.

The NBR approach usually does not maintain producers' context information in the ICN routers. Thus the ICN routers normally do not have the capability to select which is the best producer for certain client. Although in [14], the authors proposed to associate context information directly to content, it would cause much more overhead and bandwidth in transmitting and processing the large amount of context information in the routing tables. And the ICN routers still do not have the context information about the producers themselves, such as the load, response time, etc.

In our previous work [15], we proposed a hybrid name resolution mechanism with Home Node (HHN) that addressed the shortcomings of the SNR and NBR approaches in resolving IoT data names and selecting proper producer to return data back to the client. Each content is assigned with a Home Node. The context information of the producers is only propagated to the Home Node of the content, which will act as the virtual host of the content to the rest of the network. The ICN routers still follow the name-based routing approach, but only need to maintain the interface to reach the Home Node of each content. Thus all the content requests will eventually reach the Home Node, which then selects the proper producer based on the client's criteria and the producers' contextual information maintained locally and forwards the request directly to the selected producer. The above procedure is shown in Fig. 1 with an exemplary network topology, which

will be used in the rest of the paper. Such hybrid approach significantly reduces the network bandwidth in preventing the context information being propagated in the entire network. And since each ICN router is likely to become the Home Node of different contents in a distributed way, the NRS is less vulnerable for single point failure.

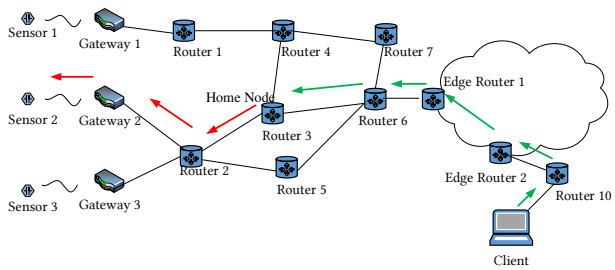

Fig. 1 Hybrid name resolution and producer selection

In this paper, we continue our previous work to address how the Home Node is adjusted when a content producer is added or removed from the network in Section II. We also will discuss how the Home Node is recovered before it fails in Section III. In Section IV, we analyze the update message overhead, storage usage and node failure impact of the proposed HHN approach compared to the SNR and NBR approaches. Section V concludes the paper.

II. HOME NODE ADJUSTMENT

The Home Node of a content may need to be adjusted among the routers when a new producer appears or an existing producer disappears from the network. The principle used in this paper in adjusting the Home Node of a content is to try to make the Home Node reside in the shortest distance away from all the producers. But this principle is not mandatory if it takes a great effort to achieve it, e.g. computation overhead, communication overhead among routers, etc. Thus the Home Node of a content may remain unchanged when a new producer appears or an existing producer disappears from the network as far as the Home Node can reach all of the producers. However, it is the best if the Home Node can be adjusted with the appropriate overhead. In this section, we discuss how the Home Node can be adjusted to meet the above requirements.

A. Appearance of New Producer

A new producer of a content may appear and attach to a gateway or router that already announced the existing producers.

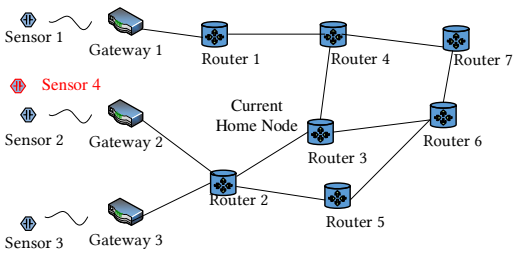

Fig. 2 New producer shares a same gateway as an existing producer

As shown in Fig. 2, the new producer shares the same attachment point as an existing producer, i.e. the Sensor 4 attaches to the Gateway 2 as the Sensor 2. A new producer of a content may appear and attach to a new gateway. As shown in Fig. 3, the Sensor 4 attaches to the Gateway 4, which connects to the local area network via the Router 2.

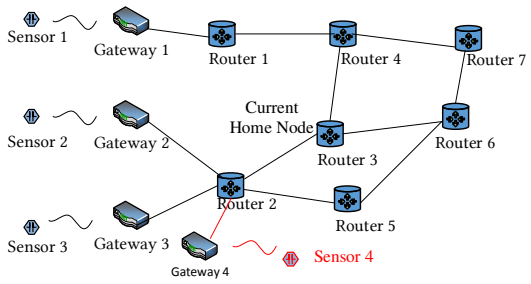

Fig. 3 New producer attaches to a new gateway

In either scenario, the following steps are taken:

- Step 1: The new producer announces its appearance to the attached gateway by a new producer notification message. This message can be sent as an interest message with an special field which indicates that this is a new producer notification. It is forwarded in the same way as the normal interest message towards the Home Node, the difference is that the Home Node processes the message and does not forward any further. In Fig. 2, the Sensor 4 notifies to the Gateway 2, while in Fig. 3, the Sensor 4 notifies to the Gateway 4.
- Step 2: The Gateway forwards the information of the new producer to its connected router. In Fig. 2 and Fig. 3 , the Gateway 2 or Gateway 4 forwards to the Router 2.
- Step 3: The Router 2 creates a new producer notification message and forwards to the Router 3 based on the FIB. The new producer notification message can leave out the contextual information of the new producer to reduce the communication overhead.
- Step 4: When the new producer notification message reaches the Router 3, it will trigger the Router 3 to calculate the total distance between itself to all the producers, including the new one. Since the Router 3 as the current Home Node keeps records of the paths from itself to the existing producers, the Router 3 can discover that the Router 2 has the shortest total distance to all the producers in both scenarios as shown in Fig. 2 and Fig. 3.
- Step 5: The Router 3 sends the Home Node adjustment request message to the Router 2 to move the Home Node of the content to the Router 2.
- Step 6: The Router 2 accepts the request, and requests all the context information of the producers to be moved to itself. Since the Router 2 happens to have

the context information of the new producer, the Router 2 does not need to retrieve this information. Otherwise, the new Home Node needs to retrieve the context information of the new producer from the first router that the new producer connects to through the gateway. In the meantime, the Router 2 updates the FIB entry for the content by pointing to itself.

- Step 7: The Router 2 is required to broadcast a FIB propagation message to update the rest of the network about the Home Node adjustment for the content. The FIB propagation message can be triggered by accumulating enough number of changes, in order to reduce the network bandwidth in flooding the messages and the processing overhead of the routers in the network.

B. *Disappearance of Existing Producer*

An existing producer of a content may disappear from the network, due to the battery outage, or because it is disabled by the operator, etc. When such scenario happens, the Home Node of the content should be notified and may be adjusted. For example, as shown in Fig. 4, the Sensor 1 as an existing producer of the content becomes deactivated, thus no longer serves as a producer of the content. Before this happens, the following steps are taken:

- Step 1: The Sensor 1 or its attached Gateway 1 sends an producer deactivation notification message to the Home Node. This message can be sent as an interest message with an special field which represents this is an producer deactivation notification. It is forwarded the same way as the normal interest message towards the Home Node, the difference is that the Home Node processes the message and does not forward any further.
- Step 2: In the scenario shown in Fig. 4, the Gateway 1 forwards the producer deactivation notification message to the Router 1. The Router 1 forwards it to the Router 4 based on the FIB, which forwards to the Router 3, then to the Router 2.
- Step 3: The Router 2 removes the Sensor 1 from its local database for the content. The removal of the Sensor 1 does not trigger the Home Node adjustment since the Router 2 remains the best candidate for Home Node, given the existing content producers: Sensor 2, Sensor 3, and Sensor 4.

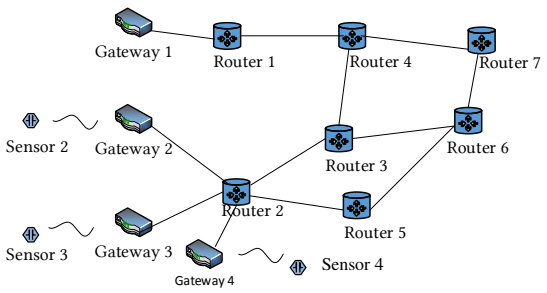

Fig. 4 Existing producer disappears from the network

III. HOME NODE RECOVERY

A router may be disconnected from the network due to node failure. For example, as shown in Fig. 5, the Router 3 detaches from the network. In the example, the Router 3 is the Home Node for the content, whose producers are the Sensor 1, Sensor 2 and Sensor 3 (Note, we remain using the producer deployment as shown in Fig. 1). Before this happens, the Router 3 needs to find a new Home Node for the content it serves. The Router 3 may choose its direct neighbors Router 6, Router 4 or Router 2 as the new Home Node. But the Router 3 needs to make sure that the three producers are reachable by the chosen new Home Node. The Router 3 can choose one of them as the new Home Node for the particular content, and move all the information of the content to it before the Router 3 becomes out of function. The Router 3 needs to send the Home Node transfer request message to the new Home Node (e.g. Router 6) for the content, which includes the content name. The Router 6 agrees by replying with a Home Node transfer acceptance message to the Router 3. If the Router 6 does not agree due to its limited storage to accompany more new content, it can reply with a Home Node transfer decline message. The Router 3 can send such request to the Router 4, or Router 2 until one of them accepts the request. The Router 3 needs to carry out the above procedures for each content it serves as the Home Node. Alternatively and more efficiently, the Router 3 may split its maintained content to 3 groups. Each group of the content can be transferred to either Router 4, Router 6 or Router 2.

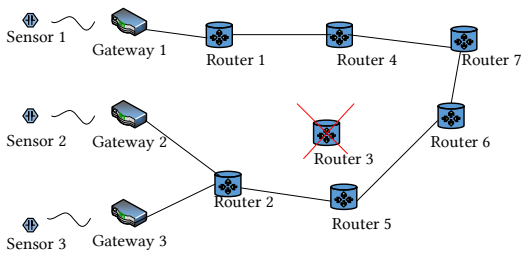

Fig. 5 Home node failure

IV. PERFORMANCE ANALYSIS AND COMPARISON

In this section, we analyze and compare the performance of the proposed HHN with the existing NBR and SNR approaches.

A. *Update Message Overhead*

The update message overhead is due to the change of content reachability, which may include producer appearance or disappearance, the producer's contextual information updates etc.

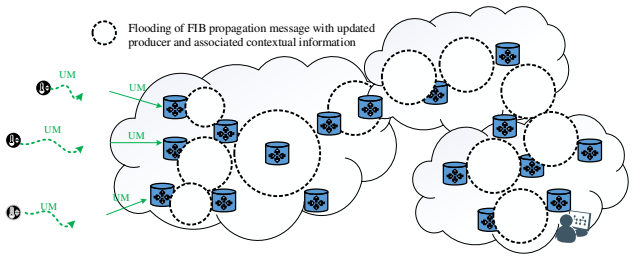

Fig. 6 Update message propagation in the NBR

Fig. 6 shows the propagation of update messages (UM) in the NBR approach. In order to let the client be able to properly resolve and reach the content data, the FIB propagation message with the updated producer and associated contextual information needs to be flooded in the entire network.

Fig. 7 shows the propagation of control messages in the SNR approach. The update messages need to be propagated in the name resolution server overlay.

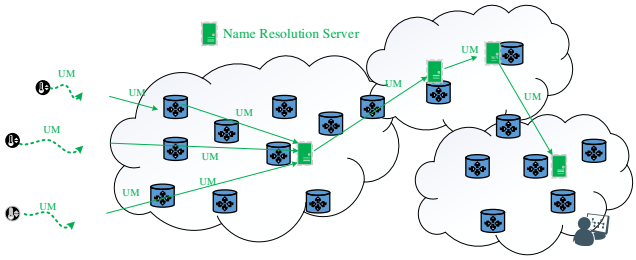

Fig. 7 Update message propagation in the SNR

In the HHN approach, the update messages reach the Home Node, which will in turn update the FIB entry but keep the contextual information in the local database. If the update messages only contain the latest contextual information of the existing producers, the name based routing tables remain the same, thus no FIB propagation is needed as shown in Fig. 8. The FIB propagation message is only flooded in the entire network when the new producer appears or the old one disappears as shown in Fig. 9, which does not contain any contextual information.

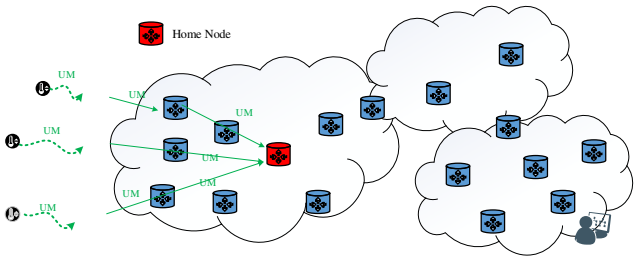

Fig. 8 Update message propagation in the HHN due to an existing producer's contextual information change

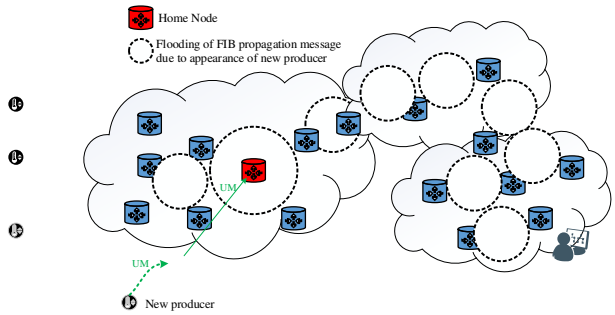

Fig. 9 Update message propagation in the HHN due to the appearance of a new producer

Fig. 10 compares the update message overhead due to the appearance of two new producers versus the average number of links in the network. The number of links determines the flooding scope, i.e. the number of hops that a FIB propagation message is forwarded in the network. On the other hand, the number of links also indicates the size of the network, given that the average probability that two nodes are connected is the same for different network sizes. In the SNR approach, for larger size of the network, the content publishing message with the two new producers' information will be transported in more number of hops in order to reach the name resolution overlay servers. Our proposed HHN scheme generates the smallest update message overhead compared to the NBR and SNR approaches.

Fig. 11 shows the update message overhead of three approaches due to the context information update of the existing producers. We keep the number of producers, the network size, the number of links in the network, the number of hops to reach the furthest name resolution overlay server to be the same, the resulting update message overhead can be calculated. The proposed HHN approach shows significantly less overhead compared to the NBR and SNR approaches. The updated contextual information of the producers only need to be sent to the Home Node of the content, which is an in-network ICN router and has the smallest sum of distances from/to all the producers.

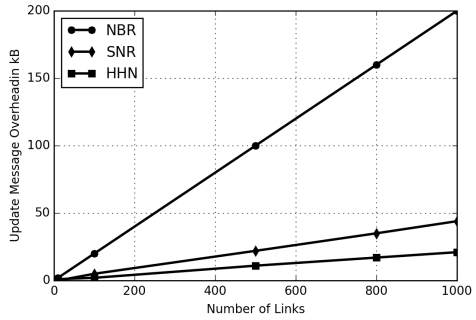

Fig. 10 Update message overhead due to new producer appearance vs. number of links

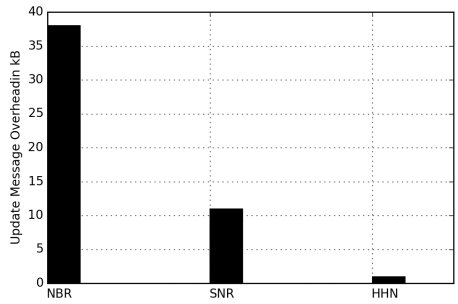

Fig. 11 Update message overhead due to context change

B. *Storage Usage*

The SNR approach typically needs to maintain two databases: name to locator mapping in the name resolution overlay and routing tables in the routers on the data forwarding plane. The NBR needs to maintain different databases: name routing table and optionally breadcrumbs for

reverse routing of content back to the client. In order to achieve producer selection function, either the name resolution servers in the SNR, or the ICN routers in the NBR are required to maintain the relevant context information of all the content in the storage additionally.

In the SNR, each server in the name resolution overlay needs to maintain one copy of the contextual information for quick producer selection in the client's local domain. Alternatively, the SNR can also maintain only one copy of the contextual information in one of the name resolution servers (e.g. a server in the core network). But it will increase the latency experienced by the client and impose higher risk of name resolution and producer selection failure due to the single point failure at this server.

In the NBR, each ICN router has to maintain the contextual information of all content in the network, because each ICN router is in charge of selecting a paper forwarding face (producer selection is performed in the meantime) and routing the interest message. Overall, the NBR approach has the most information duplication, which is the reason why the HHN approach is proposed to improve the storage efficiency.

The proposed HHN spread the contextual information to ICN routers without duplication, but still realizing the name resolution and producer selection function with least latency. In the other words, HHN only needs to maintain one copy of the contextual information in total. Each ICN router in the network may be responsible in storing the context information for a small group of content in the network.

C. Node Failure Impact

Nodes involved in the SNR approach are the name resolution overlay servers, while the nodes involved in the NBR and HHN approach are routers which route messages based on the name based routing tables maintained locally. Node failures in the SNR approach may cause some content resolution to fail even though the content is available. This problem does not exist in the NBR and HHN approach because other alternative paths can be discovered to bypass the failed ICN routers, given the assumption that the network is still connected.

To each content, there is a special node in the network, which is the Home Node of the content in the HHN approach. If the failure happens to this node, the recovery procedure needs to be taken place, which was discussed in Section III. Since the Home Nodes for different contents are assigned to be different ICN routers near to the producers, which means that each such ICN router is only in charge of managing a small portion of the contents in the network, the HHN approach is very robust and less venerable to the single point failure compared to the SNR.

V. CONCLUSIONS

The proposed name resolution approach ensures resilience to node failures. Before a Home Node fails, it is able to transfer the name records to another ICN node. The name resolution approach provides accurate and up-to-date information on how to reach the producer(s) of requested content with minimum overhead in propagating the update information. The Home Node can be adjusted due to producer appearance/ disappearance to guarantee the accurate resolution with minimum delay. The name resolution approach is extremely scalable and distributed to support a large number of content objects as well as users, who may access the system through various connection methods and devices. The proposed name resolution approach also provides the function to select proper content producer among multiple available ones. It is especially useful and important for IoT applications, in which multiple sensor devices may be deployed to produce the same content information. It can satisfy the client's requirement in latency or cost, achieve load balancing among sensor devices, etc.

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