Performance Evaluation of Named Data Networking Based Ad Hoc Network Focusing on Node Moving

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***Abstract*—We have been studying on applying the named data networking technology to mobile ad hoc networks. We suppose a type of ad hoc networks that advertise versatile information in public spaces such as shopping mall and museum. The proposed approach is a hybrid one where a proactive routing is used in the producer side network, and a reactive routing is used in the consumer side network. The proactive routing here has a feature that only the name prefix advertisement is focused on. In the reactive routing, only the first Interest packet is flooded and the corresponding Data packet creates a routing entry. Although we reported some results of the performance evaluation of the proposed method previously, they are still insufficient. In this paper, we show the results of performance evaluation focusing on the node moving in the consumer side network. The results indicate that our proposal has little overhead both for Interest packet transfer and routing control.**

Keywords- Ad Hoc Network; Named Data Networking; Hybrid Routing; Proactive Routing; Reactive Routing.

I. INTRODUCTION

Recently, the Information Centric Network (ICN) is widely studied as a future Internet architecture well suited for large scale content distribution. The Named Data Networking (NDN) [1] is adopted widely as a platform for ICN research activities. The fundamental concept in NDN is the name of required content, not the address of hosts containing content. A consumer requesting a content sends an Interest packet containing the content name. A producer providing the corresponding content data returns a Data packet to the consumer. NDN routers transferring the Data packet cache the packet for future redistribution.

Originally, NDN is designed for wired network topology, but it can be effectively applied to wireless multi-hop ad hoc network topology. In wireless ad hoc network, the routing mechanism is more important research topic than wired fixed network, because network nodes move around. In NDN, the purpose of routing is how to construct Forwarding Information Base (FIB) for name prefixes, which specifies the correspondence between a name prefix and an interface called face (or a neighbor identifier) to the content with this name prefix.

In the previous papers, we proposed a new NDN ad hoc routing scheme [2][3], which is targeting at ad hoc networks providing various useful information in public spaces, such as station, shopping mall and museum. Content providers advertise helpful information for users, such as location map, advertising catalog, and exhibition details. The proposed scheme adopts a hybrid approach, which has the following features. First, in the type of ad hoc networks we suppose, a content producer side has a stable network where producers and intermediate routers are located in fixed positions. On the other hand, consumers are mobile nodes which change their locations quite often. Therefore, a proactive routing is adopted in a producer side network, because of its in-advance route setting, and a reactive routing is adopted in a consumer side network, because of its flexibility for mobility. The second is about the procedure of proactive routing. The NDN proactive routing procedures proposed so far [4]-[8] are focusing on advertising both the network topology and the name prefix. On the other hand, the proactive routing adopted in our proposal is focusing on just the name prefix advertisement. The third is about the procedure of reactive routing. The reactive routing of our proposal uses both FIB and PIT. Although the first Interest packet for a specific name prefix is flooded, the corresponding FIB entry is created by the returning Data packet and the following Interest packets for the name prefix are transferred by this FIB entry.

Although the basic idea was presented in our previous papers, the performance evaluation results described in those papers and another paper [9] are limited, because they only provide rather simple theoretical analysis and do not evaluate detailed behaviors of routing protocols.

This paper describes the detailed results of the performance evaluation for the routing control and Interest transfer overheads focusing on moving consumer side nodes. The performance evaluation is conducted with ndnSIM [10], a widely used NDN simulator implemented over the ns-3 network simulator [11]. The rest of this paper consists of the following sections. Section 2 shows the related work on NDN routing. Section 3 describes our NDN ad hoc routing protocol. Section 4 shows the implementation of the proposed protocol over ndnSIM and the results of the performance evaluation. Section 5 concludes this paper.

II. RELATED WORK ON NDN ROUTING

There are several proposals on the routing in NDN. For the wired NDN topology, the proposed named OSPFN [4] and NSLR [5] are examples introduced in an early stage. Both of them are based on the link state routing protocol, which maintains and advertises link statuses between neighbors, shares the topology information, and creates routing tables from it. The protocol in [6] is a relatively new proposal based on the link state routing considering multipath routing.

In the case of the NDN based wireless ad hoc network, both the proactive and the reactive approaches are proposed [12]. This trend is the same as the IP based ad hoc network. MobileCCN [7] and TOP-CCN [8] are examples of the proactive routing mechanism. MobileCCN can be said an

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NDN version of Routing Information Protocol (RIP) [13]. TOP-CCN is an NDN version of Optimized Link State Routing (OLSR) [14]. On the other hand, E-CHANET [15] and REMIF [16] are examples of reactive routing mechanism, which are designed based on Ad Hoc On-Demand Distance Vector routing (AODV) [17]. In these reactive routing mechanisms, FIB is not used at all, but Interest packets are flooded to find producers or cached Data packets. Only Pending Interest Table (PIT) is used for forwarding Data packets.

The proactive routing can create FIB responding to an up-to-date network topology, but has some overhead of routing control message exchange. On the contrary, the reactive routing has no overhead of routing, but has some overhead of Interest packet transfer.

III. HYBRID ROUTING PROTOCOL FOR NDN AD HOC NETWORK

A. *Overview of Proposed Routing Protocol*

We have adopted the following design principles for our hybrid NDN based routing mechanism.

- As described above, we divide a whole NDN network into the producer side and the consumer side. In the producer side, NDN nodes including producers and intermediate routers have their location fixed. So, a proactive routing mechanism is introduced in this part. On the other hand, the consumer side includes mobile nodes working as consumers or intermediate routers. Those nodes move around and the network configuration often changes. In this part, a reactive routing mechanism is introduced.
- For the producer side, our proactive routing focuses only on name prefix advertisement. It constructs a Directed Acyclic Graph (DAG) starting from each producer. An FIB entry for a specific name prefix is given by pointing upstream nodes traversing the corresponding DAG in a reverse direction. If there are more than one upstream nodes, both of them are registered in the entry and used for multipath forwarding [18].
- In order to create a DAG for a specific name prefix, the corresponding producer issues a *Name Prefix Announcement Request* (*NPAreq*) packet. It is broadcasted, and if any receiving NDN nodes are on the corresponding DAG, they return a *Name Prefix Announcement Reply* (*NPArep*) packet by unicast.
- As for the consumer side, NDN nodes do not use any control packets for routing. Instead, the FIB entry is created by the first Interest packet for a name prefix. The first Interest packet is flooded throughout the consumer side, and after it reaches some node in the producer side, this Interest packet is transferred to the producer. When the corresponding Data packet returned, a temporary FIB entry is created at the nodes in consumer side. For the following Interest packets for the same name prefix, this FIB entry is used.

B. *Communication Sequence of Proposed Protocol*

Figure 1 shows an example of communication sequence of the proposed protocol focusing on the consumer side behavior. Figure 1(a) is an example network, where the producer side nodes construct a DAG whose root is producer *node 2*. As shown in Figure 1(b), when consumer *node p* starts the content retrieval for name prefix *name*, the first Interest packet is flooded among the consumer side nodes. The Interest packet arriving at *node 6* is transferred according to the DAG, via *node 5* to *node 2*. When the corresponding Data packet returns, the corresponding FIB entry is created at *nodes q* and *p*. The following Interest packets will be transferred using these FIB entries.

IV. PERFORMANCE EVALUATION

In this section, we describe the results of performance evaluation using the ndnSIM simulator version 1.0.

A. *Simulation conditions*

Figure 2 shows the network configuration used in the simulation. In the fields of 300 m by 200 m, four producer side nodes are located in a grid configuration with 100 m distance. The location of these nodes are fixed through a simulation. In addition, ten consumer side nodes are deployed

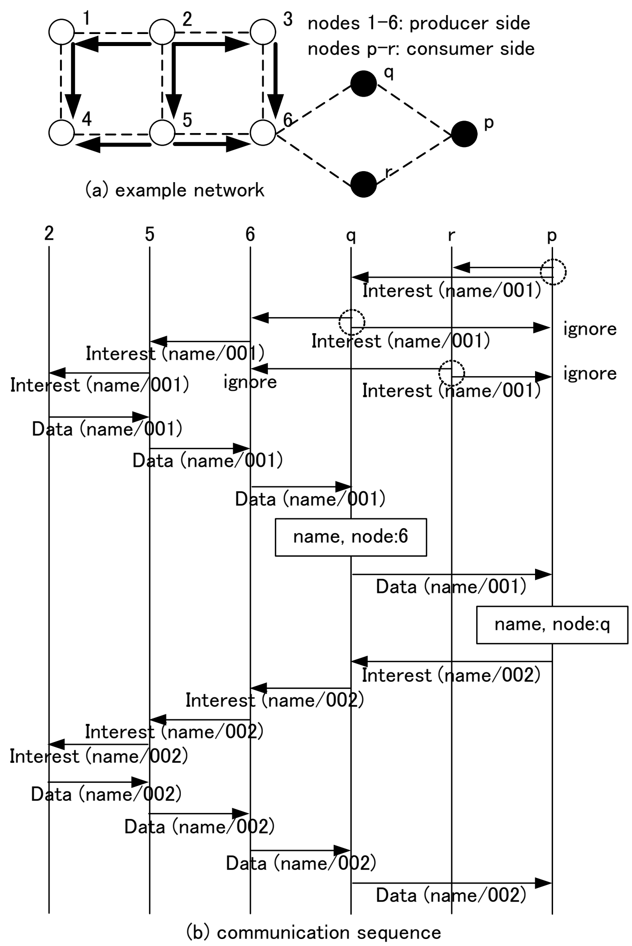

Figure 1. Example of communication sequence.

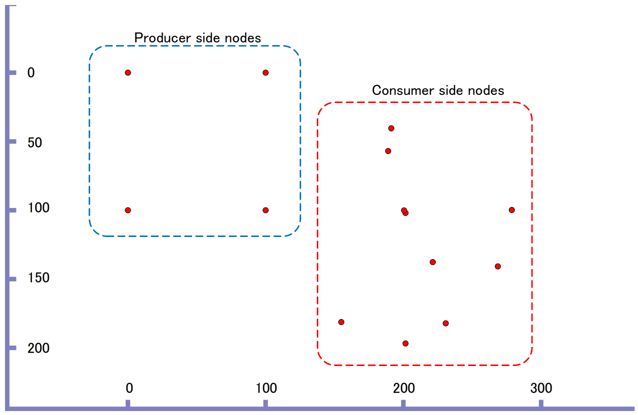

Figure 2. Network configuration for simulation.

TABLE I. SIMULATION PARAMETERS.

Radio propagation	constant speed propagation delay model; three log distance / Nakagami propagation loss model
Wifi data mode	OFDM rate 24 Mbps
Mobility model	Random work 2D model; course change at every 2 second; mobility speed = 40 m/s, 20 m/s, or 10 m/s
Consumer	Randomly selected two, four, six and eight nodes; request different content/the same content; 10.0 through 10.3 Interests/s
Producer	node at (0, 0); Data packet size = 1200 bytes
Cache size	1000 packets at each node
Evaluation	15 seconds for each simulation run; 10 seconds for Interest packet origination, and 5 seconds just for timeout retransmission

randomly with the center of (200, 100). These nodes move around according to a random walk model. All nodes communicate with each other through ad hoc mode IEEE 802.11a protocol.

The details of simulation condition are given in Table I. As for the radio propagation, we used a setting used commonly in the ns-3 simulator. The data rate in IEEE 802.11a is 24 Mbps constant. The consumer side nodes move around according to the 2 dimensional random walk model with the constant mobility speed, where nodes change their direction at every 2 second. We adopted the mobility speed of 40 m/s, 20 m/s, and 10 m/s. Those values are large as a moving speed of human, but they are adopted for changing the wireless connection during a 15 second simulation run. Among the producer side nodes, the node located at the position (0, 0) works as a producer. As for the consumer side, two, four, six, or eight nodes work as consumers requesting different content or the same content. If each consumer requests different content, the Data packet caching is not effective in the simulation. If the same content is used for all consumers, the caching will be used effectively.

B. Evaluated methods and their implementation details

The methods evaluated in this paper are the proposed method, REMIF (simplified version), and NDN over UDP/IP ad hoc network with OLSR routing (OLSR based NDN). OLSR based NDN is used in order to estimate the performance of TOP-CCN, because the exchange of Hello and TC (Topology Control) messages corresponds to that of CA packets in TOP-CCN. On the other hand, OLSR based NDN uses the IP based routing in intermediate nodes as shown in our previous paper [19], and even if all consumers request the same content, the Data packet caching is not effective. So, when the same content is used, OLSR based NDN can be used to estimate an IP based ad hoc network.

The following describe the details of the implementation of three evaluated methods.

(1) REMIF

FIB is not specified, and Interest packets are always transferred with the destination address set to broadcast MAC address ("ff:ff:ff:ff:ff:ff"). On the other hand, PIT is used for returning Data packets to consumers. When a new Interest packet is received, the incoming face and the source MAC address of the Interest packet is stored in a new PIT entry. Since it is possible that the identical Interest packet is received via a different path, the duplication is detected by the Interest nonce stored in this PIT entry. A retransmitted Interest packet from a consumer contains the same nonce as the original Interest packet. In order to handle retransmitted Interest packets properly, a PIT entry for which a Data packet is not returned needs to be discarded when its lifetime expires. The lifetime of a PIT entry is set to the lifetime of Interest packet, 500 msec in this evaluation.

Since REMIF uses the broadcast in transmitting Interest packets, we observed a mis-ordering problem. The details are described in our previous papers [9][19]. In order to avoid this problem, we took the following way. In the PIT handling in the *ForwardingStrategy* class, when a Data packet is received, the records for incoming faces and outgoing faces are cleared, and then the PIT entry is erased by setting the PIT entry pruning timer. In the default, this value is set to 0 and the PIT entry is removed instantly. In this evaluation, we set this timer value to 50 msec. This means that our implementation ignores duplicate Interest packets received during 50 msec from the Data packet handling.

(2) Proposed method

In the performance evaluation here, we focus on the protocol behavior and the routing overhead when consumer side nodes move around. So, as for the routing protocols for producer side nodes, we set the FIB by hand before simulation runs start.

We implemented the FIB handling behavior in consumer side nodes by extending the REMIF program described above. At first, when a consumer side node receives an Interest packet, it looks for an FIB entry matching the name prefix included in the Interest packet. If there are no entries, it creates a new entry for the name prefix with the default face and the broadcast MAC address. A consumer side node transmits s the received Interest packet according to the corresponding FIB entry.

When a consumer side node receives a Data packet, it registers the face from which the packet is received and the source MAC address of the data frame containing the Data packet in the corresponding FIB entry, if the MAC address in the entry is the broadcast MAC address.

When the network configuration of consumer side nodes changes, the FIB needs to be reconstructed. We implemented this mechanism in the following way.

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- In order to detect the route change in consumer side nodes, we use the PIT entry pruning timer described above. When this timer is expired, the incoming and outgoing faces in the PIT entry examined. If they remain in the entry, we can decide that the Data packet corresponding to an Interest packet is not returned. These checks are executed in the PIT related class (the *PitImpl* class, specifically).
- If this timeout occurs consecutively (three times in our implementation), we decide that the route change occurs. Then, the outgoing face in the PIT entry is checked and, if the outgoing face has a unicast MAC address, the routine for clearing FIB entry in the *ForwardingStrategy* class is called.
- In the clearing FIB entry routine, the MAC address is set to the broadcast MAC address.

(3) OLSR based NDN

The OLSR based NDN method is implemented the approach using the TCP/IP protocol stack under NDN. We can use the *OlsrHelper* class supported in the ns-3 simulator and the *IpFaceHelper* supported in the ndnSIM simulator. It should be noted that the calling of "Bing()" in the "*CreateOrGetUdpFace*()" method in the *IpFaceStack* class needs to be commented out, in ndnSIM version 1.0.

C. Evaluation results

(1) Overview

We conducted three kinds of performance evaluation. The first is that using two consumers by changing the mobility speed. The second is that changing the number of consumers from two to eight with 20 m/s mobility speed. In these evaluations, individual consumers retrieve their own content, that is, no cache mechanisms are used. The third one is that where all consumers request the same content. In this case, cache mechanism is effective for REMIF and the proposed method. The conditions of the third evaluation is similar with that of the second evaluation.

In the evaluation for REMIF and the proposed method, we evaluated the following features, by changing the mobility speed of consumer side nodes or the number of consumers:

- the total number of Interest packets originated from consumers,
- the total number of Interest packets actually sent from consumers (including retransmissions),
- the total number of Data packets consumers received,
- the total number of forwarded Interest packets by all nodes, and
- the total number of forwarded Data packets by all nodes.

In the evaluation for OLSR based NDN, we evaluated the following features:

- the total number of Interest packets originated from consumers,
- the total number of Interest packets actually sent from consumers (including retransmissions),
- the total number of Data packets consumers received, and
- the total number of Hello and TC messages used in OLSR.

As for the sending interval of Hello and TC messages, we selected 0.5 sec and 1 sec, respectively. In order to establish routing information in the evaluation of OLSR based NDN, we introduce 5 second period before starting the content retrieval. In other word, simulation runs for OLSR based NDN take 20 seconds, consisting of 5 seconds for routing information setting, 10 seconds for Interest packet origination, and 5 seconds for timeout retransmission.

(2) Results of evaluation by changing mobility speed

Figures 3 through 5 show the results of the first performance evaluation. In the following figures, we normalize the number of packets by the total number of Interest packets originated from consumers. By adopting this normalization, the number of Data packet received by consumers shows the data delivery ratio.

Figure 3 shows the total numbers of Interest and Data packets that consumers sent and received actually. The number of Interest packets is one through four times of that of the original Interest packets. The three methods have a similar tendency. Similarly, the number of Data packets that consumers received, i.e., the data delivery ratio, is 1 except the case of OLSR based NDN with 40 m/s speed, in which case the value is 0.99. With the 5 second retransition period, almost all Interest packets are satisfied by the corresponding Data packets.

Figure 4 shows the numbers of Interest and Data packets forwarded by all nodes in the network. Except the Interest packets in REMIF, the numbers are several times of the original Interest packets. The number of forwarded Interest packets in REMIF is more than twenty times of that of the original Interest packets.

Figure 5 shows the overhead of OLSR, i.e., the numbers of Hello and TC messages during the Interest origination and retransmission period. From this result, it can be said that the overhead of OLSR routing messages is not very large.

Those results with two consumers show that although the number of forwarded Interest packets in REMIF is large, the data delivery rate is high for three methods, and that the mobility speed examined here does not affect the performance so much.

(3) Results of evaluation by changing number of consumers

Figures 6 and 7 show the results of the second performance evaluation. Here, we changed the number of consumers, which request their own content, from two to eight. The mobility speed is set to 20 m/s. It should be noted that the vertical axis is logarithmic in those graphs.

Figure 6 shows the total numbers of Interest and Data packets that consumers sent and received actually. The proposed method and OLSR based NDN have a similar tendency, but the data delivery ratio is high for the proposed method. When there are eight consumers, the ratio of the proposed method is 0.85 and that of OLSR based NDN is 0.52. On the other hand, the performance of REMIF is worse than the others. In the case of eight consumers, the number of Interest packets actually sent by consumers goes to as high as

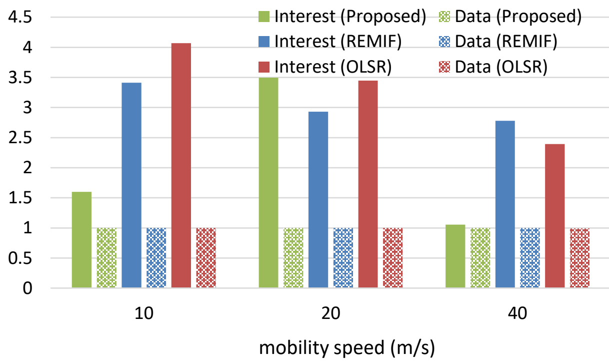

Figure 3. Numbers of Interest packets actually sent from consumers and Data packets received by consumers (normalized by originated Interests; changing mobility speed).

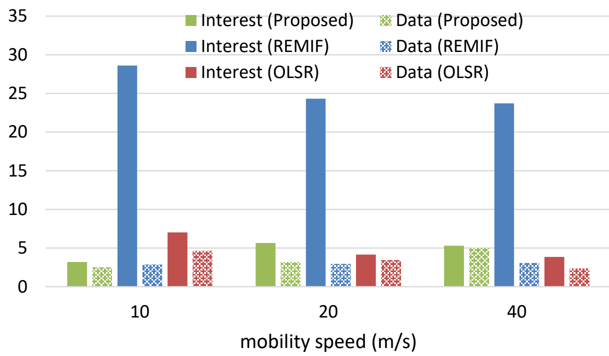

Figure 4. Numbers of Interest and Data packets forwarded by all nodes (normalized by originated Interests; changing mobility speed).

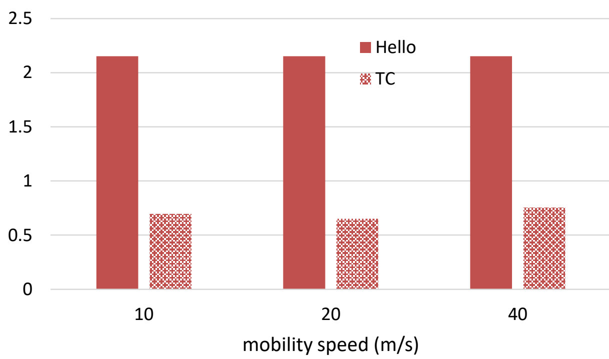

Figure 5. Numbers of OLSR Hello and TC messages (normalized by originated Interests; changing mobility speed).

32.7 times that of original Interest packets, and the data delivery ratio goes down to 0.27.

Figure 7, giving the total numbers of Interest and Data packets forwarded through the network, shows similar results. In the case of eight consumers, the total number of forwarded Interest packet is 242 times of the number of original Interest packets. The proposed method and OLSR based NDN also give similar tendency in this figure.

From the results with changing the number of consumers, it can be said that the performance of REMIF is worse than the others according to the increase of consumers requesting different content. It should be noted that the REMIF used in this paper is a simplified version, which does not include the

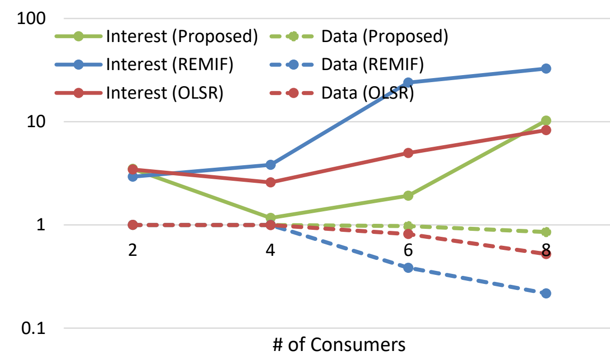

Figure 6. Numbers of Interest packets actually sent from consumers and Data packets received by consumers (normalized by originated Interests; changing number of consumers).

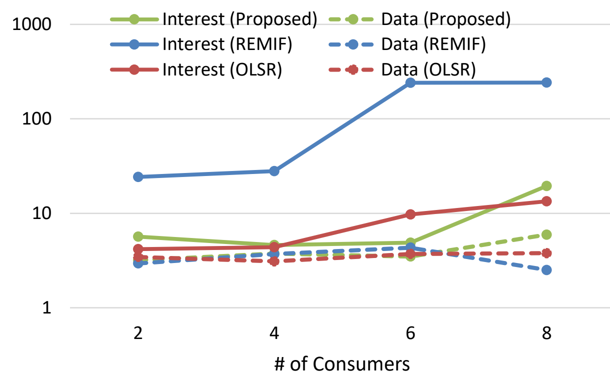

Figure 7. Numbers of Interest and Data packets forwarded by all nodes (normalized by originated Interests; changing number of consumers).

Interest suppression with deferring the Interest packet flooding randomly. But, we believe that the Interest flooding without FIB may be a problem when the number of consumers is large.

(4) Results of evaluation with Data packet caching

Figures 8 and 9 show the results of the third performance evaluation. Here, all consumers request the identical content, and therefore the Data packet cache is expected to work effectively. The cache size of each node is 1,000 packets and the other conditions are the same as in the second evaluation. As described in Section 4, the caching does not work in OLSR based NDN, and so, it indicates the performance of IP based ad hoc network in this evaluation.

Figure 8 shows the total numbers of Interest and Data packets that consumers sent and received actually. In this figure, the results of the proposed method and REMIF changed largely compared with Figure 6. The number of actually sent Interest packets is up to around twice of the original Interest packets. That of REMIF becomes less than 10 % of Figure 6 in the case of eight consumers. The data delivery ratio of the proposed method and REMIF is 1 through this evaluation. On the other hand, the result of OLSR based NDN is similar with that shown in Figure 6. In the case of eight consumers, the data delivery ratio is 0.59.

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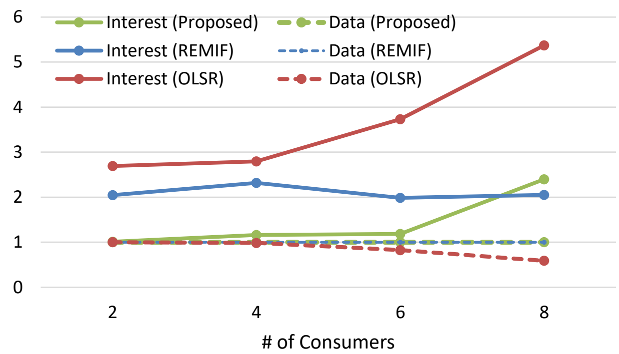

Figure 8. Numbers of Interest packets actually sent from consumers and Data packets received by consumers (normalized by originated Interests; consumers requesting same content).

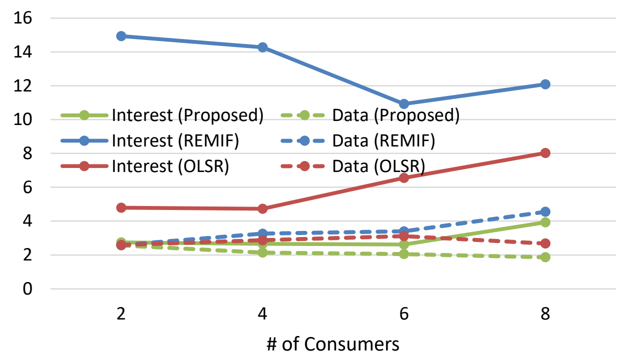

Figure 9. Numbers of Interest and Data packets forwarded by all nodes (normalized by originated Interests; consumers requesting same content).

Figure 9 shows the total numbers of Interest and Data packets forwarded through the network. In this figure, the result of REMIF changed largely from that in Figure 7, although the number of forwarded Interest packets is still largest among the three method. In the case of eight consumers, the number was 242 times of that of original Interest packets, but it decreases to 12 times when the caching works well.

From those results, it can be said that the Data packet caching can reduce the traffic largely and that the performance can be increased compared with IP based ad hoc network.

V. CONCLUSIONS

This paper showed three kinds of performance evaluation with mobile nodes which move around according to the random walk model. The results of the performance evaluation show the followings.

When the number of consumers is small, the proposed method, a simplified reactive routing (simplified REMIF), and a proactive routing (OLSR based NDN) have a similar data delivery ratio, although the number of flooded Interest packets is large in simplified REMIF. The mobility speed of consumer side nodes did not affect the delivery ratio so much. Secondly, when the number of consumers requesting different content increases, the performance, i.e., the data delivery ratio and the routing overhead, of REMIF becomes worse. The data delivery ratio of the proposed method is better than that of OLSR based NDN supposing TOP-CCN. Thirdly, when the Data packet caching works effectively, the performance of the proposed method and REMIF is improved largely. The OLSR based NDN, which does not use the caching and therefore emulates IP based ad hoc network, has poor data delivery ratio than NDN based method. So, it can be said that the data caching is effective.

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