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Bandwidth-based QoS-aware Multisource Architecture for Information-Centric Wireless Multihop Networks

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***Abstract*—Information-Centric Networking (ICN) is one of the representative architectures for Future Internet that focuses on content rather than IP address. Different from traditional TCP/IP networking, any node that caching content can respond to a request for the content. This property makes it convenient that multiple providers deliver different chunks of a content to a requester concurrently, which can offer more reliable network services and better load balancing. However, it may impact quality of service (QoS) because traditional end-to-end QoS control cannot be performed in this scenario. In this paper, a Bandwidth-based QoS-aware Multisource Architecture (BQMA) is proposed for Information-Centric wireless multihop networks, which performs QoS control for multisource routing, forwarding, reservation procedure, and provider selection functions. Simulation results demonstrate the effectiveness of the proposed architecture.**

I. INTRODUCTION

Information-Centric Networking (ICN) is a new paradigm for the Future Internet where content, instead of hosts, is the first-class network entity [1]. In ICN, consumer sends request packets to request content by name, regardless of the address of node providing the content. Any node that stores the requested content can reply with data packets, which follow the way of request packet back to the consumer. Although most of works on ICN focus on wired environments, recent works [2]–[4] have proved that it is also a promising networking solution for wireless networks. On the other hand, majority of traffic over the Internet has shifted to video content, and the fraction of Internet traffic consumed by video is predicted to reach 82% in 2021 [5]. However, due to the factors, such as limited bandwidth, unreliable channel, and poor signal, wireless networks present unique challenges to provide quality of service (QoS) for multimedia applications.

We consider the Information-Centric wireless multihop networks, in which any nodes that cache content can be providers. This multisource property makes it convenient that multiple providers deliver different chunks of a content to a requester concurrently. Although this multisource communication paradigm could offer more reliable network services and better load balancing, it may not guarantee the quality of service because the traditional end-to-end QoS mechanisms cannot be applied for multiple paths/trees. The data flows from different providers may contend for the bandwidth, and be subject to quite different network behavior. In this paper, we propose a QoS-aware mechanism for multisource multimedia application in Information-Centric multihop networks.

QoS is an agreement to provide guaranteed services, such as bandwidth, delay, jitter, and packet delivery rate to users. However, supporting more than one QoS constraints make the QoS problem NP-complete [6]. Therefore, we only consider the bandwidth requirement in the QoS-aware architecture for supporting multimedia application in Information-Centric wireless multihop networks.

In this paper, a Bandwidth-based QoS-aware Multisource Architecture (BQMA) is proposed for Information-Centric wireless multihop networks. We propose a distributed method to measure available bandwidth of nodes. To meet the challenge of estimating available bandwidth, we build a novel network-structured Markov chain model to describe the dependency among nodes of the network. The proposed architecture provides multisource routing, forwarding, reservation procedure, and provider selection functions. The bandwidth, the most important resource in wireless networks, is taken into account in all of the functions. Simulation results show that, by considering bandwidth, BQMA is efficient and effective in terms of throughput.

II. RELATED WORK

A number of researches have applied ICN into wireless networks. ECHANET [4] implements routing, forwarding, and transporting functions on top of the IEEE 802.11 wireless networks. Interest and Data packets are broadcasted. The forwarding of these packets exploits a counter-based scheme [7] to avoid redundancy and control scalability. Amadeo et al. [8] focused on the design, implementation and performance analysis of two schemes as a representative of the main CCN [9] forwarding philosophies. In the two schemes, the blind scheme only relies on packet overhearing and waiting timers to support multi-hop forwarding while counteracting the broadcast storm. Kim et al. [10] analyzed the performance of reliability and energy efficiency of both broadcast and unicast delivery schemes in Information-centric mobile ad hoc networks.

To the best of our knowledge, most existing Information-Centric schemes for multihop wireless networks have not considered the available bandwidth for path selection. However, deciding whether the wireless networks satisfy the bandwidth

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requirement of the data flow to be transmitted is one of the most important issues for providing quality of service. In BQMA, we will consider the bandwidth in all functions of the architecture.

Multipath routing has been used in wireless ad hoc networks to provide better load balancing and error resilience. Many multipath routing protocols, such as [11], [12], have been proposed to discover multiple paths. Reference [11] establishes and utilizes multiple routes of maximally disjoint paths. It uses a per-packet allocation scheme to distribute data packets into multiple paths of active sessions. Reference [12] computes multiple loop-free and link-disjoint paths. It proposed multipath extensions to a well-studied single path routing protocol AODV. However, all of these multipath routing protocols discover multiple paths between a single source and a single destination, and there still exists correlation between these paths due to wireless interference. In contrast, our work focuses on multipath from multiple providers to one requester. In addition, we have considered the bandwidth contention between multiple paths.

There have been several studies of multisource mechanisms in wireless networks. For example, Ding et al. [13] focused on the problem of finding the maximum number of high-quality and independent paths from the user to the servers or peers for video on-demand request by considering the effect of wireless interference. They proposed two efficient heuristic path discovery algorithms. However, this solution focused on multichannel multiradio wireless mesh networks, whose enhanced channel diversity increases the network capacity. In contrast, our work focuses on single radio wireless multihop networks, in which the effect of wireless interference is more seriously.

Amadeo et al. [14] propose a baseline CCN framework for the support of reliable retrieval of data from multiple wireless producers which can respond to the same Interest packet. The results confirm the benefits of the conceived solution, that save bandwidth, while maximizing data diversity and shortening the collection time. However the proposal focuses on single-hop wireless scenarios. Therefore, it does not tackle multi-hops wireless networks as we conducted in this paper.

III. BQMA PROTOCOL

In BQMA, bandwidth is taken into account in all functions of the architecture, including multisource routing, forwarding, reservation procedure, and provider selection. We firstly present how to measure available bandwidth. Based on the measurement of available bandwidth, the working process consists of two procedures: content discovery and content delivery.

A. Distributed measurement of available bandwidth of nodes

1) Definition of available bandwidth: Available bandwidth (AB) of a node is defined as the redundant bandwidth that the node can use to forward new traffic. Before explaining the available bandwidth definition, we first discuss two important ranges: transmission range and carrier sensing range. The maximum range that a node can receive and decode a packet correctly is defined as transmission range. While the maximum range that a node can sense the transmission of other node is defined as the carrier sensing range. As shown in Fig. 1, node A can communicate with node B, since the distance of these two nodes is smaller than transmission range. While node A cannot directly communicate with node C, since its distance is larger than the transmission range. However, node A's available bandwidth can be consumed by node C. For example, when node C is sending packet to node D, due to the carrier sensing, node A cannot receive and decode packet from node B.

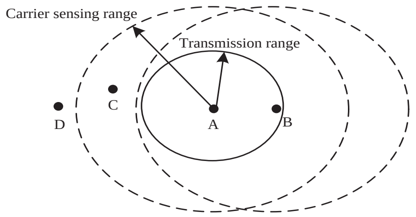


Fig. 1. Transmission range and carrier sensing range.

Since a node's carrier sensing range is about twice of its transmission range [15], a node's 1-hop and 2-hops neighboring nodes are considered as its Carrier-Sensing Neighboring Nodes (CSNN) in our mechanism. We assume that all the links are symmetric links. If node i is one of node j's CSNN nodes, node j also is one of node i's CSNN nodes. Hence, a node can send/forward a packet only when all of its CSNN nodes are not sending packet. Suppose the probability that node j as well as all of its CSNN nodes are not sending packet is $P_{idle}(j)$, then the available bandwidth of node j, $AB_n(j)$, is defined as:

$$AB_n(j) = P_{idle}(j) * MTR_j \tag{1}$$

where MTR_j is node j's maximum transmission rate which is calculated as follows.

The application's data rate must be translated into the corresponding channel bandwidth requirement. In this translation, the protocol overhead in the MAC layer and networking layer must be considered. According to the IEEE 802.11 protocol, each application data packet, the MAC layer performs an RTS-CTS-DATA-ACK handshake. Therefore, the transmission time (T_{data}) required for data packet is:

$$T_{data} = T_{difs}+T_{rts}+T_{cts}+\frac{L+H}{DR}+T_{phy}+T_{ack}+3T_{sifs}+T_{\overline{backoff}} \tag{2}$$

where L is data packet payload size, H is the packet header length, DR is the node's data rate. T_{rts}, T_{cts}, and T_{ack} represent the time for transmitting RTS, CTS, and ACK packets, respectively. T_{sifs} and T_{difs} denote the interframe spaces SIFS and DIFS. T_{phy} is the transmission time for PHY overhead. $T_{\overline{backoff}}$ is the average contention backoff time. Then, node j's maximum transmission rate (MTR_j) is:

$$MTR_j = L/T_{data} \tag{3}$$

Obviously, a node j should get the probability value $P_{idle}(j)$ to evaluate the available bandwidth values. In order to get the probability value for each node, we build a novel network-structured Markov chain model to describe the dependency among nodes of the network.

2) Model of network-structured Markov chain: The basic definitions of this model are presented as follows:

- We define three states for each node: "idle" (state 0), "sending" (state 1), and "interfered" (state 2). A node is in "idle" state if neither the node itself nor its CSNN nodes are sending/forwarding a packet. A node is in "sending" state if it is sending/forwarding a packet, while none of its CSNN nodes is sending/forwarding a packet. Otherwise, a node is in "interfered" state if any of its CSNN nodes is sending/forwarding a packet.
- Let $\alpha_t(i,0)$ be the probability that node i is "idle" at time t, $\alpha_t(i,1)$ node i is "sending", and $\alpha_t(i,2)$ node i is "interfered".
- We define model parameter $p_{i,k}$ as the probability that node i transits from state k to state 1 ("sending"), where "k" = 0, 1, 2.
- Let N be an adjacency matrix, $n_{i,j}$ be the (i, j)th element of N. If node i and node j are carrier-sensing neighboring nodes, $n_{i,j}$ = 1; otherwise, $n_{i,j}$ = 0. Specially, all of the main diagonal elements of N are set to 0, i.e., $n_{i,i}$ = 0, for all i.
- Let q_i be the probability that node i sends or forwards a packet when all of its CSNN nodes are in "idle" state, and $q_i^{'}$ the probability that node i does not send or forward a packet in this case.

A node can start to send a packet if the current state is "idle" or "sending", which is independent to the previous state of the node. In this sense, we assume that the sending state of the node has the temporal Markov property. The current state of the node is "idle" if the current states of its self and all its CSNN nodes are "idle", which is independent to the current states of all other nodes. In this sense, we assume the idle state of the node has the spatial Markov property. Specifically, we have the following three relations:

$$\alpha_t(j,2) = \sum_{i\neq j}\sum_{k=0}^{2}\alpha_{t-1}(i,k)p_{i,k}n_{i,j} \tag{4}$$

where $\alpha_{t-1}(i,k)$ is the probability that the current state of node i is in stake "k", $p_{i,k}$ is the probability that node i transits from state k to state 1 ("sending"), then the probability that node i will be in state "sending" in the next time unit is $\alpha_{t-1}(i,k)p_{i,k}$. Hence, Eq.(4) means that node j will be "interfered" at the unit time t if any of its CSNN nodes is sending/forwarding a packet.

$$\alpha_t(j,1) = [1-\alpha_t(j,2)]q_j \tag{5}$$

where $\alpha_t(j,2)$ is the probability that node j is ąřinterferedąś, then $1-\alpha_t(j,2)$ is the probability that node j is not ąřinterferedąś (i.e., node j is in state 0 or 1), q_j is the probability that node j sends or forwards a packet when all of its CSNN nodes are in "idle" state. Therefore, $\alpha_t(j,1)$ in Eq.(5) means node j may send/forward a packet if none of its CSNN nodes is sending/forwarding a packet.

$$\alpha_t(j,0) = 1-\alpha_t(j,1)-\alpha_t(j,2) \tag{6}$$

where $\alpha_t(j,1)$ is the probability that node j is in "sending" state (state 1), $\alpha_t(j,2)$ is the probability that node j is in "interfered" state (state 2). Therefore, $\alpha_t(j,0)$ in Eq.(6) represents that node j is in "idle" state (state 0). i.e., neither node j nor its CSNN nodes are sending/forwarding a packet.

Substitute Eq.(6)into Eq.(4), and Eq.(5)into Eq.(4), we can obtain the forward formulas:

$$\alpha_t(j,2) = \sum_{i\neq j}[q_i^{'}p_{i,0}+q_ip_{i,1}]n_{i,j}+\sum_{i\neq j}\alpha_{t-1}(i,2)[p_{i,2}-(q_i^{'}p_{i,0}+q_ip_{i,1})]n_{i,j} \tag{7}$$

or

$$\alpha_t(j,2) = \sum_{i\in\{i^{'}:n_{i^{'},j}=1\}}\{(q_i^{'}p_{i,0}+q_ip_{i,1})+\alpha_{t-1}(i,2)[p_{i,2}-(q_i^{'}p_{i,0}+q_ip_{i,1})] \tag{8}$$

Denote

$$\beta_t(i) = (q_i^{'}p_{i,0}+q_ip_{i,1})+\alpha_{t-1}(i,2)[p_{i,2}-(q_i^{'}p_{i,0}+q_ip_{i,1})] \tag{9}$$

then Eq.(7) and Eq.(8) become $\alpha_t(j,2) = \sum_{i\neq j}\beta_t(i)n_{i,j}$ and $\alpha_t(j,2) = \sum_{i\in\{i^{'}:n_{i^{'},j}=1\}}\beta_t(i)$.

The parameters used to calculate $\beta_t(i)$ in Eq.(9) can be obtain by means of statistical methods. Obviously,$\beta_t(i)$ is the predicted probability that node i interferes its CSNN nodes at time t. Then from Eq.(7) or Eq.(8) we can see that, to calculate $\alpha_t(j,2)$, node j only needs to collect $\beta_t(i)$ from its CSNN nodes, for all $i\in X_j$, where $X_j = \{i: n_{i,j} = 1\}$ is the set of node j's CSNN nodes. Then, it can calculate the values of $\alpha_t(j,0)$ and $\alpha_t(j,1)$ by Eq.(6) and (5).

At last, the value of available bandwidth of node j can be obtained by

$$AB_n(j) = P_{idle}(j)*MTR_j = \alpha_t(j,0)*MTR_j \tag{10}$$

B. Content discovery

The working process of BQMA consists of two procedures: content discovery and content delivery. In the content discovery procedure, a request packet (REQ) is broadcasted by a requester when it requests some content. Intermediate nodes rebroadcast the REQ packet if they do not have the corresponding content. Once an intermediate node receives a REQ packet, it waits for a time period before it decides to rebroadcast the packet. The length of the waiting time period is related to its available bandwidth value. An intermediate node with higher available bandwidth value has a shorter waiting time. If it overhears the same REQ packet transmitted by another node during the waiting time, it quits the rebroadcast process; otherwise, it rebroadcasts the REQ packet. In this way, the request packets can be forwarded along paths with larger available bandwidth to the providers.

For this purpose, we introduce a random waiting period T_{REQ} for intermediate nodes before they rebroadcast REQ packet. For node i it can be calculated by:

$$T_{REQ} = rand\{0, \left\lceil (1 - \frac{AB_i}{MTR_i}) CW_{min} \right\rceil\} slotTime \quad (11)$$

where MTR_i is node i's maximum transmission rate, AB_i is its available bandwidth value, CW_{min} is the minimum contention window, and $slotTime$ equals to the slot time in IEEE 802.11 MAC layer. We use CW_{min} as the maximum waiting time (multiplied by $slotTime$) to make the nodes with higher available bandwidth values have shorter waiting time. In this way, lower available bandwidth nodes have longer waiting time. They may overhear the same REQ packet transmitted by another node with a higher probability.

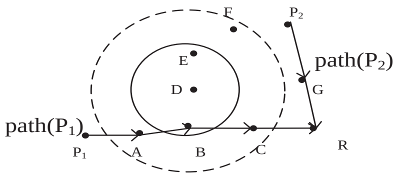


Fig. 2. An example of bandwidth consumption and reservation procedure.

C. Reservation procedure, provider selection and content delivery

Once a provider node receives the REQ packet, it can send back the targeted content with data packets. BQMA uses on-demand route discovery with source routing, similar to DSR. REQ packets record the routes they have passed. Providers send content data packets back with the route in their header. However, the number of the providers found in the content discovery procedure is unknown at this time. We propose reservation procedure and provider selection mechanisms to address this problem.

Let r_d be the data rate to be sent from a provider to a requester. The data flow will consume the bandwidth of path nodes as well as their carrier-sensing neighboring nodes. Denote the set of node i and its carrier-sensing neighboring nodes by $BCN(i)$, and the set of nodes in the data flow path by $PATH$. Let nodes P and R be the provider and requester of $PATH$, respectively. Then $BCN(i) \cap (PATH \backslash R)$ is the subset of nodes in $BCN(i)$ that send or forward the data flow packets. Note that, node R only receives the data flow packets and does not need to forward them. Therefore, the data flow consumes the bandwidth C_i at node i determined by [15]:

$$C_i = |BCN(i) \cap (PATH \backslash R)| r_d \quad (12)$$

As shown in Fig.2, the requester R has found two providers P_1 and P_2 with two paths: $path(P_1)$ and $path(P_2)$. We explain the bandwidth consumption with data flow from P_1 (i.e. $path(P_1)$) and node D. Suppose node P_1 is going to send a data flow with data rate r_d to node R. The data flow is relayed by nodes A, B, and C. For node D, $BCN(D)$ = {E, F, A, B, C D}. $PATH \setminus$ R = {P, A, B, C}. Then |BCN(D)∩ (PATH\ R)| = 3, and the bandwidth C_D consumed in node D is 3* r_d.

The main purpose of the reservation procedure is to determine whether the data flow with the required data rate can be admitted by the discovered paths from the requester to the found providers. Because it is possible that only one provider is found in the content discovery procedure. Each provider performs the reservation procedure to find whether its path can support the data flow. If a path cannot support the required data rate, it should get the maximum data rate which this path can admit. In the requester side, a rate allocation algorithm for the providers can be performed based on the received paths bandwidth information.

Each provider may receive multiple REQ packet copies which represent different paths. It selects a path from the first arrived REQ packet copy to perform the reservation procedure. Other paths can be regarded as candidate paths. The required transmission rate r_d of the data flow is contained in the REQ packet.

After a provider selected the path, it generates a Bandwidth Request (BREQ) packet. The BREQ packet carries the full route of the selected path and the bandwidth requirement r_d. Then, the provider (e.g., node $P1$ and $P2$ in Fig.2) performs reservation procedure by sending the BREQ packet along the selected path. Every node (including providers) in the path will send the BREQ packet to its 1-hop and 2-hops neighbors (likely to be its carrier-sensing neighboring nodes). Each node i that receives the BREQ packet calculates the data flow's bandwidth consumption C_i by Eq.(12) and compares it with its available bandwidth AB_i. If $AB_i \geq C_i$, it records the data flow label and reserves bandwidth for the data flow at node i by letting: $AB_i \leftarrow AB_i$ - C_i.

Otherwise, it gets the maximum data rate (r_{dm}) which this path can support at this node by calculating r_{dm} = AB_i / |$BCN(i)$∩$(PATH \backslash R)$| and unicasts a Bandwidth Update (BUPD) packet which contains the value r_{dm} to the initiator node (e.g., the nodes in $path(P_1)$ and $path(P_2)$) of the BREQ packet. Since there may be several nodes unicast the BUPD packet to the initiator node, it selects the minimum one r_{dm-min} i.e., the minimum data rate that its carrier-sensing neighboring nodes can support. For example, the initiator node receives n BUPD packets with: r_{dm1}, r_{dm2}, ..., r_{dmn}, the minimum one is r_{dm-min} = min{r_{dm1}, r_{dm2}, ..., r_{dmn}}. Note that, a node forwards the BUPD packet only if it has not sent any BUPD packet or the data rate value in the previous sending/forwarding BUPD packet is larger.

For example, consider $path(P_2)$ in Fig.2, provider P_2 sends a BREQ packet to its 1-hop node F and 2-hop node E to perform the reservation procedure. If nodes E and F have enough bandwidth, they record the data flow label and reserve bandwidth for the data flow by letting: $AB_E \leftarrow AB_E$ - C_E and $AB_F \leftarrow AB_F$ - C_F. Otherwise, the nodes that have not enough bandwidth should get the maximum data rate which this path can support at this node. For example, node E and F both do not have enough bandwidth. They calculate their maximum data rate values that can admit by: r_{dE} = AB_E / $|BCN(E) \cap (path(P_2) \backslash R)|$ and r_{dF} = AB_F / $|BCN(F) \cap (path(P_2) \backslash R)|$. Node F generates a BUPD packet containing r_{dF} and sends to node P_2. Then, Node F receives a BUPD packet generated at node E containing AB_E. It resends the BUPD packet to node P_2 only if $r_{dE} < r_{dF}$. At last, node P_2 receive maximum data rate value(s) $\{r_{dF}\}$ or $\{r_{dE}, r_{dF}\}$. It selects the minimum one $r_{dm-min} = r_{dF}$ or r_{dm-min} = min$\{ r_{dE}, r_{dF} \}$.

After the initiator node has performed the reservation procedure, it sends the BREQ packet to the next node in the path. The length of the timeout period in initiator node is determined by the channel propagation delay, the transmission time of the bandwidth update packet, and the computation time. The BREQ packet contains r_{dm-min} or r_d (in the case that the initiator node does not receive any BUPD packet). All of the nodes in path will perform the reservation procedure.

After requester receiving the paths information, it allocates the data rate on the paths for providers. The rate allocation, which determines the sending rate for each provider, runs in a centralized fashion in the requester side. In this paper, we use the average rate of requested content instead of its instantaneous rate. We focus on the rate allocation on the multiple paths multiple providers for the requested content, such that the sum of rates on the multiple paths satisfies the total rate requirement of the requesting content.

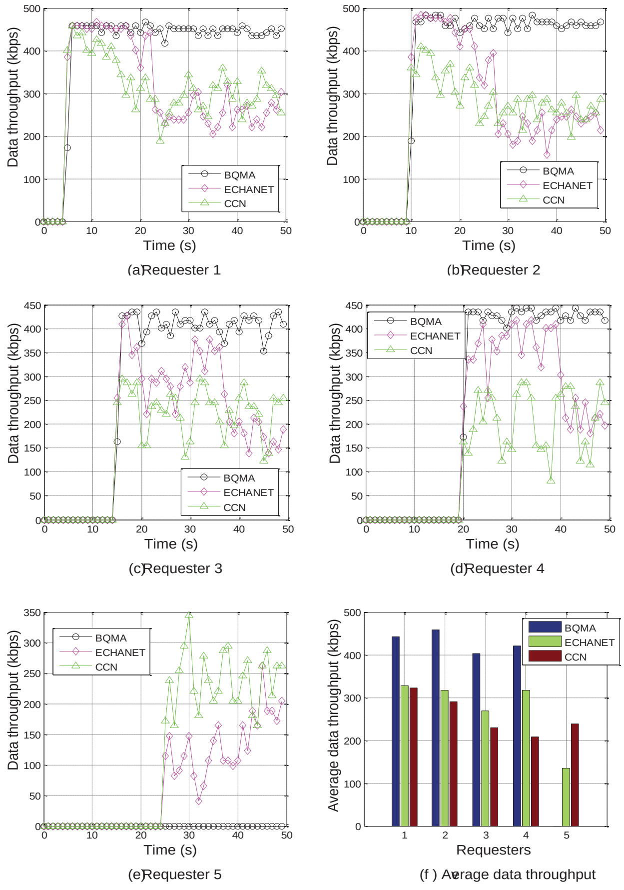
Suppose there are m providers. The paths information (i.e., r_{dm-min} or r_d value) in the corresponding BREQ packets are: r_{d1}, r_{d2}, ..., r_{dm}. Then, it checks whether it is satisfied:

$$r_d \leq \sum_{k=1}^{m} r_{dk} \tag{13}$$

If Eq.(13) is true, it means that the bandwidth requirement of the requesting content can be satisfied, i.e., any results $r_{dk}^{'}$, k = 1, ...,m, that satisfy:$r_d = \sum_{k=1}^{m} r_{dk}^{'}$ and $r_{dk}^{'} \leq r_{dk}$ can be used by the providers. Then, requester selects a result. It tells providers their data rates and what data packets they should send by sending a Bandwidth Response (BRSP) packet to each provider. After that, providers can start to send data packets to requester concurrently. If Eq.(13) cannot be satisfied, which means the discovered paths have not enough bandwidth, the requester sends a BRSP packet to each provider to release the bandwidth values reserved in all paths' nodes and their carrier-sensing neighboring nodes. As the BRSP packet is sent from one node to another in the paths, their 1-hop neighbors also can overhear the BRSP packet. They all release the bandwidth for this data flow. Then, the 1-hop neighbors broadcast a BRSP packet to their own 1-hop neighbors. In this way, all of the nodes in the path and their carrier-sensing neighboring nodes will release the reserved bandwidth. The requester tells one provider to select another candidate path and the reservation procedure is performed again at all of the providers. This procedure will continue until it is successfully performed, or there is no candidate path that meets the bandwidth requirement of the data flow.

TABLE I. Request starting times and data rate requirements.

Requesters	1	2	3	4	5
Request starting time (s)	5	10	15	20	25
Data rate requirement (kbps)	458	482	440	441	456



(a)Requester 1 (b)Requester 2 (c)Requester 3 (d)Requester 4 (e)Requester 5 (f) Average data throughput

Fig. 3. Throughputs of the three architectures. (a) Requester 1. (b) Requester 2. (c) Requester 3. (d) Requester 4. (e) Requester 5. (f) Average data throughput.

IV. EVALUATION

A. Simulation Setup

In order to evaluate the performance of BQMA, simulations are implemented in a network simulator OMNeT++. In all simulation experiments, we use IEEE 802.11g as the node's PHY and MAC protocol. We consider a static wireless multihop network with 50 nodes uniformly distributed at random in a 1000m*1000m square area. Three Access Points (APs) are placed at the three corners of the square area, which are the original providers of contents.

There are 100 different contents in the original providers at the beginning of the simulations. Five requesters are randomly selected among the 50 nodes in the square area and download the contents from the providers. Table I shows the request starting time and the data rate requirement of the five requesters. The content requesting rate follows a zipf-like distribution.

We compare BQMA against another two promising Information-Centric architectures: basic CCN [9] and

ECHANET [4]. CCN is one of the most representative network architectures of Future Internet. In CCN, the five requesters request content with the same starting times and requesting data rates as BQMA in Table I . In ECHANET, Interest and Data forwarding exploits a packet suppression technique to avoid redundancy and to control scalability. In addition, transport functions are designed to provide reliability and Interest rate control at the consumer side. The reliability is realized by Interest retransmission. Interest rate control function regulates the Interest rate. In the simulation, the requesting data rate is determined by both the Interest rate control function in ECHANET and Table I , i.e., the requesting data rates meet the requirement of transport functions and are no larger than the values in Table I.

B. Performance

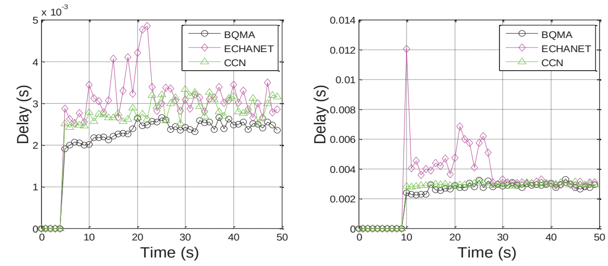
In this simulation, we evaluate the throughput and delay performances of the three architectures.

As shown in Fig.3a-d, the requests of requesters 1- 4 in BQMA are admitted, and the throughputs of these requests are maintained all the time. Moreover, the throughputs of these requesters are much higher than that of ECHANET and CCN. Fig.3e shows that the requester 5 is rejected in BQMA for lack of enough bandwidth resource in the network. However, since there are no rejection mechanisms, requester 5 is admitted in ECHANET and CCN. In addition, the throughput of ECHANET is higher (lower) than that of CCN when the network bandwidth is (not) enough.

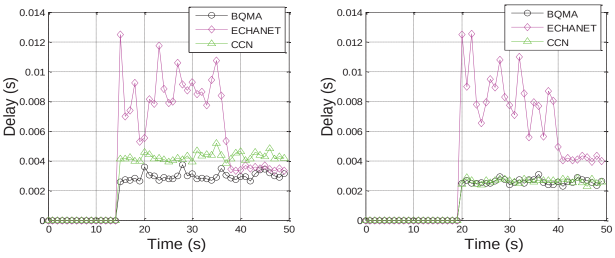
These results show that our architecture outperforms ECHANET and CCN in the throughput metric. It is because that our architecture considers the network bandwidth in all of its functions. The bandwidth aware forwarding mechanism for request packets make BQMA prefer to the higher bandwidth to provider route in the content discovery procedure. In addition, it has a reservation procedure in the content delivery procedure to guarantee that there is enough bandwidth for the admitted requester(s). On average, as shown in Fig.3f, the throughputs of requesters 1- 4 of BQMA are always guaranteed and much higher than that of ECHANET and CCN. Since there are Interest retransmission and Interest regulate functions in ECHANET, its throughput is higher than that of CCN when the bandwidth is enough. However, the Interest retransmission make contention and collision worse when there is not enough bandwidth in the network. Hence, the throughput of ECHANET is lower than that of CCN in this case.

The delay is defined as the average time that data packets delivered from a provider to the requester in BQMA and CCN. Since requester resends Interest packets to re-request the unsuccessfully received data packets in ECHANET, the delay defined in this architecture is: if the data packet is received successfully at the first request time, it is defined as the same as BQMA and CCN; otherwise, it is defined as the time elapsed from when the requester requests for the second time until it receives the data packet.

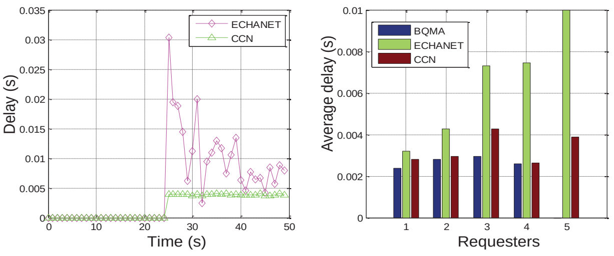
As shown in Fig. 4a-d, the delay of BQMA is kept stable as requesters 1- 4 admitted into the network. From Fig. 4f, the average delays of BQMA are lower than that of ECHANET and CCN. Hence, our architecture also outperforms ECHANET and CCN in the delay metric. The reason is similar with the throughput performance. By considering the bandwidth in BQMA, it makes the data flows have enough path bandwidth. Data packets that transmitted in these paths occur less contention and collision, which make them arrive at the requester as soon as possible. The delay of CCN is lower than that of ECHANET. It is because that all of the data packets are sent from the same optimal provider for one requester and there is no retransmission in CCN.



(a) Requester 1 (b) Requester 2



(c) Requester 3 (d) Requester 4



(e) Requester 5 (f) Average delay

Fig. 4. Delays. (a)Requester 1. (b)Requester 2. (c)Requester 3. (d)Requester 4. (e)Requester 5. (f)Average delay.

V. CONCLUSION

In this paper, a bandwidth-based QoS-aware multisource architecture for Information-Centric wireless multihop networks has been proposed. A bandwidth-aware forwarding for request packet in intermediate nodes was proposed in the content discovery procedure. Request packet may find multiple providers for a requester. We proposed reservation procedure and provider selection mechanism for this multisource communication paradigm. Simulation results demonstrated the effectiveness of the proposed mechanism.

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