Energy-Efficient Content Retrieval in Mobile Cloud

You Lu*, Biao Zhou#, Lung-Chih Tung*, Mario Gerla*
*Computer Science Department, UCLA
*Los Angeles, CA 90095, USA
*{youlu, dragond, gerla}@cs.ucla.edu
#EADP Data, Electronic Arts
#biazhou@ea.com

Ashwin Ramesh, Lohith Nagaraja
Computer Science Department, UCLA
Los Angeles, CA 90095, USA
{ashwinr89, lohithn}@cs.ucla.edu

ABSTRACT
Mobile cloud computing (MCC) has recently been drawing increased attention in academia as well as industry. Content retrieval is a critical service, for many mobile cloud applications and in turns relies on other resources and tools, e.g., internal storage, content searching and sharing, etc. Previous studies have shown that conventional ICN interest query schemes and content searching architectures, if not properly designed, can cause significant performance degradation and energy consumption, especially for large scale MANETs.

In this paper, we specifically address the scalability and energy efficiency of the content retrieval scheme in mobile cloud computing. We propose a direction-selective forwarding scheme for the content query method that decreases traffic overhead and energy cost caused by duplicate copies of the query packets. We also advocate the parallel search method of multiple caches to increase the hit rate.

Simulation experiments show that the proposed scheme yields significant improvements in efficiency and scalability for the content retrieval in large scale MANETs.

Categories and Subject Descriptors
C.2.2 [**Computer-Communication Networks**]: Network Protocols

General Terms
Design, Performance.

Keywords
Mobile Cloud, Content Retrieval, Interest Dissemination

1. INTRODUCTION
Mobile ad hoc networks are most effective in dynamic environments where network infrastructure is not readily available or not adequate. Applications include coalition military operations, disaster recovery and emergency operations, and vehicular communications. As an example, in the battlefield the UAVs usually carry situation awareness data information frequently queried by ground soldiers or other coalitions. Since the UAV is not always connected, the ground troops will retrieve the data from other soldiers who previously cached these contents. Moreover, the cached contents are periodically refreshed by the UAVs.

In general, tactical and vehicular MANETs must support various services such as communication, storage, and computing for a range of applications, much in the way of what we call mobile clouds. One challenge in mobile cloud design is the ability to manage and serve queries to the large amount of contents and resources distributed among different nodes.

In current Internet, the information-centric network (ICN) is designed for content search and retrieval. An alternative approach is the IP-based computer network architecture. In ICN, users only focus on the content they are interested, they need not know where this content is stored and carried. We assume content is identified by a unique name. Content retrieval follows the query-reply mode. Content consumer spreads his Interest packet through the network. When matching content is found either in the content provider or intermediate content cache server, the content data will trace its way back to the content consumer using the reversed route of the incoming Interest.

Several existing ICN proposals have been studied and implemented in Internet and MANET test bed. CCN [1] and NDN [2] are two popular designs for the ICN implementation in Internet. Vehicle-NDN [3] and MANET-CCN [4] are two examples for the ICN architecture design in mobile ad hoc network, which can address the dynamic topology change for content retrieval. All of them keep the broadcast scheme through all interfaces to request the interested content name. It is accepted as the fastest method for the Interest dissemination to search the content name among the connected network, but also costs more energy on the broadcast transmission.

One major design challenge of the content retrieval in mobile cloud is the energy-efficient Interest dissemination scheme. Especially for MANET, the dynamic network topology and intermittent connectivity are sensitive to the traffic load. Two common approaches to disseminate the Interest packet to the entire network are intelligent broadcast and probabilistic forwarding. They try to reduce the duplicate copies of Interest packet that each node received to decrease the traffic overhead. However, both solutions will spread the Interest packet to the entire network until the edge, and every single node in the network will be delivered at least one copy of the Interest packet. These solutions are only minor lightweight than the naive flooding, and will suffer from the scalability problem in a large scale MANET.

In this paper, we propose an energy-efficient content retrieval scheme to enhance the performance of the mobile cloud computing. We specifically address the scalability and energy efficiency of the Interest dissemination for large scale MANETs. We propose a direction-selective forwarding scheme for the Interest dissemination phase to decrease the traffic overhead of the duplicate copies of the Interest packet and save the transmission energy. Note that not every node in this scheme will receive the Interest packet. There are some missing gaps in the network where the Interest will not be delivered to. But these gaps don't contain high degree nodes or giant component of the MANET. We advocate performing the parallel search in which content requester selects several agents by random-walk to conduct the proposed direction-selective Interest dissemination scheme parallel. A content provider delivers several copies of his content data by random-walk to his neighbor's caches. The evaluation results show

MCC'13, August 12 2013, Hong Kong, China

that the proposed content retrieval scheme is capable of retrieving any content in the large scale MANET with high hit rate and low traffic overhead.

The rest of the paper is organized as follows. Section 2 is the related work. Section 3 describes the design of the proposed energy-efficient content retrieval scheme for mobile cloud in detail. Section 4 discusses the system model and performance analysis concerns. Section 5 presents the results from extensive performance experiments. Section 6 concludes the paper and points out the future work.

2. RELATED WORK

In this section, we first introduce the general idea of information-centric network, and review the content retrieval methods in Internet and mobile ad hoc network. We also analyze the problems of content retrieval in mobile cloud application. Finally we compare our approach with the existing designs and techniques.

Information-centric network is an alternative approach to the architecture of IP-based computer networks. The basic principle is that user only needs to focus on his interested content data, rather than having to reference a specific, physical location where that data is to be retrieved from. ICN differs from IP-based routing in three aspects. First, all content is identified or named by the hierarchical naming scheme. Name becomes the object of request. Second, carefully designed caching system through the entire network helps the content distribution and provides the native features to help many other applications, e.g., multicast. Third, the packet communication follows the form of query-reply mode. User (content requester) spreads his interested content name as the "Interest" packet through the network. Once the "Interest" packet hits the content name in any intermediate cache server or the media server (content provider), the content data packets will be forwarded back to the content requester along the reversed incoming route of the Interest.

A number of previous studies focused on the ICN with high level architectures and provided sketches of the required components. Content-centric network (CCN) [1] and named data network (NDN) [2] are two implemented proposals for the ICN concept in Internet. Their components including FIT, PIT, and Content Store form the caching and forwarding system for the content data in Internet application. However, neither the CCN nor NDN can be deployed directly in the mobile ad hoc network, since the dynamic network topology and intermittent connectivity causes the difficulty to maintain the caching and forwarding scheme. Several mobile ICN architecture designs have been proposed for the mobile ad hoc scenario, e.g., Vehicle-NDN [3] for the traffic information dissemination in vehicular networks, and MANET-CCN [4] for the tactical and emergency application in MANETs. One of the challenges for content retrieval in mobile cloud network is the design of Interest dissemination scheme. It is obvious that the naive flooding method causes large traffic overhead and energy cost during the content request process. Researchers have proposed a number of improved forwarding protocols aiming at reducing the flooding overhead. Two typical categories of them are back-off timer based intelligent broadcast and probability based probabilistic forwarding.

Intelligent broadcast, also referred to as smart broadcast, is a position-based protocol aiming at the maximization of the one hop progress of the Interest packet dissemination and minimization of the forwarding delay, e.g., enhanced multi-hop vehicular broadcast (MHVB) [5], road-based directional-broadcast [6], and effective broadcast [7]. It is accompanied by a mathematical model providing a means to set the protocol's parameters optimally. Each node within the source's transmission range will compute a back-off timer before forwarding the message. The duration of this back-off timer is related to the relative geo-distance to the source. So a node far away from the source gets a short back-off value, and becomes the first one to relay to the source with message forwarding. The other nodes with a longer back-off timer will cancel their scheduled transmission upon hearing this forwarded message. The back-off timer based intelligent broadcast significantly decreases the overlap area of the packet forwarding and reduce the duplicate copies of the Interest packet. It also guarantees that every node in the network will receive at least one copy of the Interest packet.

The probabilistic forwarding is a further improved intelligent broadcast method, e.g., epidemic broadcast [8]. Similar to the intelligent broadcast, it setups a back-off timer based on the distance to source. During each broadcast interval, extended by the waiting time, the repeaters count the duplicate messages they received from their front and back. At the end of the waiting time, they enter a decision process instead of immediately sending their Interest packet. So the forwarding decision at the end of each interval is based on the duplicate messages during the waiting time. And then it will compute the probability of keeping the message alive based on a mathematical model. The decision process favors those nodes with an unbalanced message count, which means they are closer to the edge of the source's transmission range. The object of probabilistic forwarding is the same as the intelligent broadcast that they always try to spread the Interest packet to the entire network and keep the minimum traffic overhead.

Both the intelligent broadcast and probabilistic forwarding have the same drawbacks in the mobile content retrieval application. First, the Interest packet will be propagated to every node in the network. If the content data only has few copies in the network, this entire network spreading is redundant and inefficient obviously. Second, even if some intermediate nodes (e.g., cache server) match the Interest and reply with the content data, the content request will still be broadcasted to the edge of the network and cannot be terminated before the end.

Our work differs from all these studies in several aspects. First, the forwarding decision is not made individually by the relay node. It's controlled by the last forwarding node at previous hop. Second, we forward the Interest packet along some specific directions/quadrants in order to achieve low traffic overhead and low energy cost. Third, we don't guarantee that every node in the network will receive at least one copy of the Interest packet. But if the Interest dissemination scheme is properly designed, we can reach a relatively high hit rate with a lower traffic overhead of duplicate copies of Interest.

3. PROTOCOL DESIGN

In this section, we first give the common assumptions which drive some of the design decisions of the protocols. After that, we describe the design of our content retrieval scheme for mobile cloud in detail.

3.1 Assumptions

In this paper, the following assumptions are made.

- One of the primary factors considered in content retrieval scheme is the geo-location of the various nodes such as the sender, receiver and the relay nodes. We assume Global Positioning System (GPS) infrastructure would be available, which would help us to get the coordinates associated with a particular node at a given point of time.
- Also we assume the topology under consideration is bi-directional thus facilitating two way communications.

- In the given topology, node-id is used as the unique identifier for a given node in the mobile cloud.
- The hierarchical naming scheme in ICN is used in mobile cloud to identify the content data carried by nodes.
- We follow the current design of the content caching scheme in mobile ICN [3-4].
- Each node starts with a unique content, and requests are made randomly for any of these contents from any of the nodes.

3.2 System Initialization Phase

To initialize the system, each node in a network of size N duplicates its content list through a random walk of size M starting from itself, and setups a freshness timer. These copies stored in the caches of the nodes during random walk can decrease the forwarding times of the Interest packet before hitting the content to save the energy. The factor M depends on the topology of the network. Generally, it is related to the network size, i.e., $M = f(N)$ where N is the number of nodes in the network. After the freshness timer runs out, the content provider will refresh the M duplications for any data update. The freshness timer duration depends on the application requirement. After the content list replication is complete, to start a request, an Interest packet is generated by the user and implanted through a random walk of size M starting from the requester. After that, each node that has the same Interest packet starts parallel process of the direction-selective dissemination described in section 3.4. We analyze the value of M in section 4 and give the simulation result in section 5.

3.3 Packet Format

In this paper, four types of packet formats are used, as shown in Table 1.

Table 1: Packet types

Packet type	*Description*
INT	Interest packet
ACK	Acknowledgement packet
CMD	Command packet
CNT	Content data packet

1) INT packet format

The INT packet is used by the sender node to express a request for content by the Interest name. The Interest packet is forwarded by the relay node after appending the path history with its own node-id and geo-location, as shown in (1). The path history is a list of node-id, which records each hop along the transmission. Before sending out the Interest packet, the relay node adds its node-id in the path history.

INT: {interest_name, geo-location, path_history<id1, id2 …>} (1)

2) ACK packet format

The ACK packet is used by the Interest receivers to indicate acknowledgement and send other information back to the Interest packet sender (either the original requester or a relay node). The information incorporated into the ACK packet helps the Interest packet sender to choose an appropriate relay node for the next round forwarding. The information added by the Interest receiver includes its node-id, geo-location, and the duplicate count of the Interest packet that the node has received expressing the same Interest, as shown in (2).

ACK: {node-id, geo-location, dup_INT_#} (2)

3) CMD packet format

The CMD packet is used by the Interest packet sender to notify a chosen node to forward the Interest packet in the next round. The next relay node would be decided based on the information received from the ACK packets. The CMD packet is broadcasted to one hop neighbors and carries a list of relay node-id, as shown in (3).

CMD: {relay_node_list} (3)

4) CNT packet format

The content packet is used to reply the Interest packet and carry the content data to the requester. A reversed path history is attached into the content packet, which indicates the return path to the requester, as shown in (4).

CNT: {content_data, reversed_path_history<… id2, id1>} (4)

3.4 Direction-Selective Dissemination

The direction-selective dissemination for content query in mobile cloud can be described as an iterative approach in which the Interest packet is forwarded one hop at a time until it hits the content in cache server or content provider. The dissemination process consists of four steps as described in pseudo code 1.

Pseudo code 1*: Selective Directional Dissemination*

```
Step 1:
INT packet is generated.
Add sender's id into INT.
Divide the area into four quadrants.
Send out the INT.
Step 2:
Receive and cache the INT.
Count the duplicate INT #.
Check local content repository.
if (found) then
    Reply with CNT.
else
    Setup back-off time.
    Send ACK back to sender.
end if
Step 3:
Receive the ACK.
Select one relay node in each quadrant.
Send out CMD with relay_node_list.
Step 4:
Receive CMD.
Decide if forward or not.
Repeat from step 1.
Note: don't select relay node in the quadrant where the last forwarding node exists.
```

In the first step, the Interest sender initially divides its surrounding space into 4 quadrants, as shown in Figure 1(a). Four quadrants are divided by north/south/east/west directions. The sender A generates the Interest packet and adds its own node-id and geo- location into the path_history field, then broadcasts the Interest packet to all the one hop neighbors (as shown as yellow nodes in Figure 1(b)) in its transmission range.

In the second step, each Interest recipient stores the received Interest packet into its local cache and also maintains a mapping between Interest name and the corresponding duplicate count with the same Interest it ever received before (starts with 0). Once the node gets an Interest packet, the count corresponding to the Interest name is incremented. The node then checks its local content repository to see whether the content corresponding to the Interest is available. If no such content is available, the node will send back an ACK packet back to the sender, as shown in Figure 1(c).

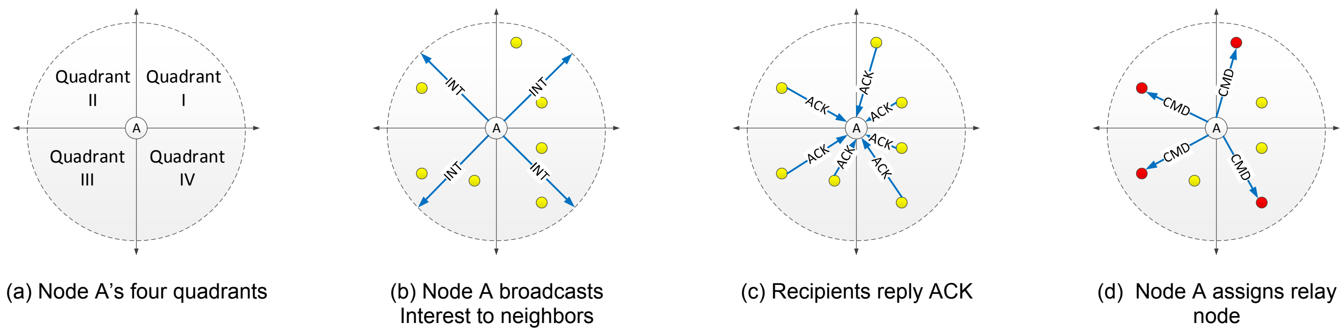

Figure 1: Direction-Selective Dissemination

In order to avoid collisions at the sender, each recipient setup a back-off timer before sending ACK, where the waiting time t_{wait} is proportional to the distance between the sender and itself, as shown in (5).

$$t_{wait} = t_{max}(1 - \frac{d}{r_{trans}}) \quad (5)$$

In (5), r_{trans} is the maximum transmission range. t_{max} is selected by a formula exponentially biased towards nodes farther away from the sender.

In the third step, after receiving the ACKs, the Interest sender chooses one node in each of its 4 quadrants as relay node. This decision is based upon the geo-location and the duplicate Interest count in the ACK packet. The node chosen in a quadrant would have the farthest distance to the sender and a value of 1 for the duplicate Interest count. This is because, farther the distance, we would be able to cover more area with respect to the sender node. Also a higher value of duplicate count indicates that the position of this recipient is covered by multiple relay nodes thus being a bad candidate in our effort to avoid increased number of Interest packet copies in the network. Once the sender has chosen relay nodes in each of its 4 quadrants, the sender would then add these selected relay node-ids into the relay node list attached in the CMD packet and broadcasts CMD packet to its one hop neighbors, as shown in Figure 1(d), where the red nodes are the selected relay node by the sender. The recipient nodes perform a lookup on the relay node list presented in the received CMD packet. If a node determines its id is presented in this list, it would then take up the responsibility of forwarding the Interest packet cached previously.

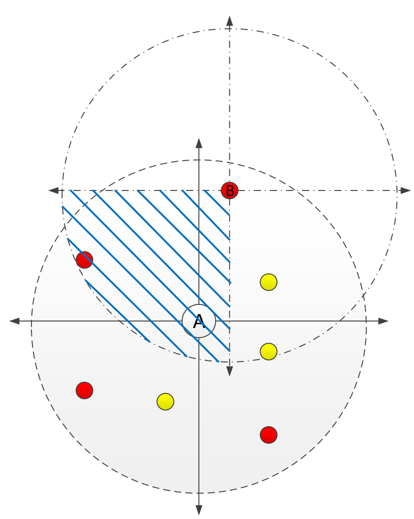

Figure 2: Node B relays the Interest dissemination

In the fourth step, the relay node adds its node-id into the path_history field of the Interest packet, and then again forwards the Interest packet in the same method: the sender in this round performs a direction-selective dissemination again. However, this time the relay node only chooses the future relay nodes in the next round from the other three quadrants expect the quadrant where the last forwarding node exists. For example, as shown in Figure 2, after the third step, node B is chosen by node A as its relay node. Then node B will repeats from the first step to the third step, but only choose the next round relay node from its quadrants I, II, and IV, expect III, since the quadrant III is the most overlap area by node A in the last round compared to other three quadrants. Also note that, since we only choose the relay node whose duplicate Interest packet count equals to one, we can avoid the formation of loops in the path history. From Figure 2 we can see that, this Interest dissemination scheme doesn't guarantee that every node in the network will receive at least one copy of Interest. But the Interest packet propagation can cover most of the giant components and high degree nodes in the network, as discussed in section 4 and shown in experiment results.

3.5 Content Data Reply and Dissemination Termination

Once the Interest packet hits the content provider or the content cache server, the content data will be transmitted back to the requester. The path_history in the received Interest packet is reversed and added into the content data packet in order to enable the nodes along the path to route the content data packets back to the requester.

Obviously, if a node has the content and reply the content data back to the requester, it will stop the Interest dissemination process. In another case, if a node is processing the Interest dissemination process, once it hears the content data replied to the Interest by other nodes, the step 3 in section 3.4 will be terminated immediately so that no more relay nodes will be selected in this direction and the Interest dissemination is terminated at this node. This method will further decrease the traffic overhead in the content request phase.

4. SYSTEM ANALYSIS

A number of studies [9][10] have shown that the structures of the existing networks have complex network characteristics, including approximate Power-law degree distributions, small diameter, tolerance to node deletions, etc. We assume that the MANET scenario in this paper satisfies the Power-law distribution in order to analyze the system performance. A distribution is said to be a Power-law distribution, if $P(k) \sim k^{-\gamma}$, where $\gamma > 0$ is called the exponent of the distribution. Sarshar, et al [11] estimated that performing the scalable parallel search in random Power-law networks with proper exponent can significantly reduce the request overhead for the traffic of Interest packet in order to find the content data.

The mobile cloud of ad hoc network in this paper also satisfies the Power-law distribution [12]. In order to find the content data, a straightforward approach to request content is to send Interest packet in intelligent broadcast or probabilistic forwarding method. All the nodes in the network need to be addressed, in the worst case, leading to $O(N)$ total requests in the network for every unique Interest packet, where N is the total number of nodes in the network. Similarly as the result in [11], the number of high degree nodes in our mobile cloud model is:

$$H \approx \frac{A}{\tau-1}(2^{\tau-1}-1)\frac{N}{k_{max}^{\tau-1}} \quad (6)$$

$$\text{where } A^{-1} = \sum_{k=k_{max}/2}^{k_{max}} k^{-\tau}$$

and k_{max} is the maximum degree of the network, $\tau = 2$ [11]. So here we have $H = O(\frac{N}{k_{max}^{\tau-1}})$.

Based on [13], the mobile cloud model also satisfies its conditions and requirements in [13]. By utilizing the direction-selective Interest dissemination proposed in this paper, the probability that the Interest packet can reach a giant component is $\frac{z}{k_{max}}$, where z depends on τ [13]. Thus, the probability that a high degree node has at least one link to the giant component is at least:

$$P > 1 - \left(1 - \frac{z}{k_{max}}\right)^{k_{max}/2} \quad (7)$$

Similar results as [13] and [14], the diameter of the connected component in our model is on the order of $O(logN)$. With the larger number of nodes in the network, the Interest packet propagates through the giant component faster, so the content data can be retrieved quicker as long as it exists in this giant component.

We can conclude that, by taking a short random walk through the network, we will reach a high degree node with higher probability. In our content retrieval scheme, the initialization phase of the proposed direction-selective Interest dissemination method is that each content consumer starts random walk with M steps to make M copies of the Interest packet at the beginning, which is the same as the content provider who makes M copies by random walk. We then run the search process in parallel. The random walk only works in the initialization phase to make M copies for both Interest and content data. When the layout is complete, the direction-selective dissemination will take the responsibility to forward the Interest packet. In this way, the Interest packet in the proposed method will hit the content provider with higher probability and reduce the querying overhead significantly compared to the current existing methods in [5-8]. We will show the experiment results of different values of M in section 5.

A major limitation of this method is that it cannot guarantee the discovery of content as 100% confidence. We must provide a fallback solution just in case that the single content is not covered by the Interest dissemination. We may choose to setup a TTL in Interest packet. The value of TTL depends on the network scale. TTL will decrease by one after each relay. If a relay nodes reaches TTL=0, it simply reply one alert message to the requester. Then the requester will turn into the traditional mode to use the intelligent broadcast for content query which leads to more traffic overhead but will guarantee 100% successful rate.

5. EVALUATION

In this section, we evaluate the performance of the proposed content retrieval scheme in a packet-level simulation with the real mobility data set.

5.1 Simulation Setup

We implemented the proposed scheme in NS-2 v2.35 network simulator. The proposed energy-efficient content retrieval protocol is installed directly above the 802.11b devices. We performed the evaluation with the mobility pattern in the Dartmouth outdoor MANET experiment data set [15]. We converted the mobility trace to a 2000*2000m^2 dimensions with 120 nodes. The results are averaged from 20 runs with different seeds with presented 95% confidential interval.

The performance is evaluated under: 1) total cost: the total number of packets that have been generated during a test. This metric reflects the overall cost of a method in the discovery of requested files; 2) prune ratio: the percentage of packets which are dropped and not forwarded over the total packets. This metric indicates the extent of messages which are not used by the nodes to propagate further; experiments 1) and 2) are conducted under M =10; 3) hit rate: the percentage of Interests that are successfully delivered to the matching content provider or cache server. This metric reflects the capability of a method to discover the requested contents.

We compared our design against the methods of naive flooding and probabilistic forwarding.

5.2 Total Cost

The total cost calculates the number of all messages involved in the Interest propagation and content retrieval. Messages like ACK and CMD are new additions in our design as compared to the traditional methods. As shown in Figure 3, the naive flooding method causes the largest total cost. While the probabilistic forwarding can significantly reduce the total cast. Our design can further decrease the total cast than all other methods.

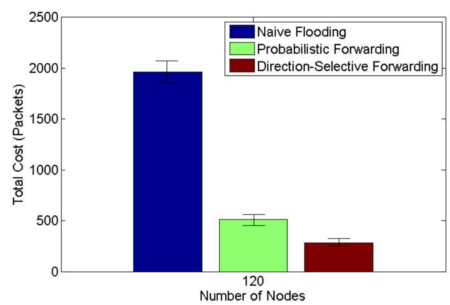

Figure 3. Total cost

5.3 Prune Ratio

In the propagation of the Interest in the network, the messages are progressively spread through the entire network. During this process, the nodes drop the received Interest packets if they are not selected as relay nodes. As shown in Figure 4, it is obvious that both the probabilistic forwarding and our direction-selective forwarding have a much higher prune ratio than the naive flooding method. And our scheme can prune even more duplicate Interest packets than probabilistic forwarding since the relay nodes are selected hop by hop based on the overlap condition, and Interest packet is propagated directionally.

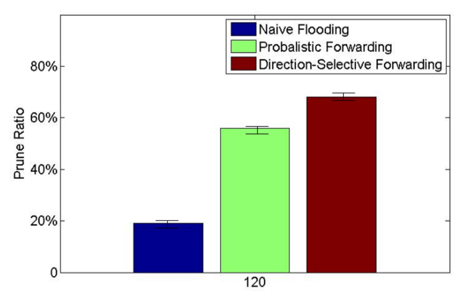

Figure 4. Prune ratio

5.4 Hit Rate

Hit rate is an indication of the successful delivery. As shown in Figure 5, the naive flooding method reaches the 100% hit rate since it floods Interest packet in the entire network. As described in section 3.2 and analyzed in section 4, we test the parameter$M$: copies of the Interest and content data in the initialization phase of our direction-selective forwarding scheme. We can see from the results that, with $M = 10$, it can reach almost 96% hit. And with the lower M value, the hit rate of our scheme decreases rapidly. $M = 0$ means that in the initialization phase the node does not replicate Interest and content data by random walk, but keeps only one unique copy in the content provider. In this case, the hit rate decreases even as low as about 64. It is because that, with the lower number of copies, it is more possible to miss the content data existing in the gap area which is not covered by the direction-selective dissemination scheme. And with the large node density in the network, more nodes exist in the gap area so that the contents on those nodes cannot be covered.

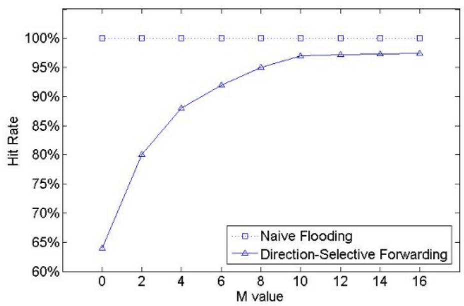

Figure 5. Hit rate with different M value

6. CONCLUSIONS

Content retrieval in mobile cloud has been an active research area. However, the scalability of the content retrieval in mobile cloud has not been assessed well. Current solutions spread the Interest packet to the entire network which will cause a large traffic overhead and will suffer from the scalability problem in the large scale MANETs. In this paper, we proposed an energy-efficient content retrieval scheme for mobile cloud to decrease the traffic overhead of the Interest dissemination and save the transmission energy. The selected relay node forwards the Interest packet along the specific direction under the control of last hop. It will significantly decrease the traffic overhead of the duplicate copies of Interest, and will terminate the further relay in a way once the content data has been found. We advocate the parallel search method, in which content requester selects several agents by random-walk to conduct the proposed direction-selective Interest dissemination scheme parallel. It decreases the impact of the missing gap from the direction-selective dissemination and increases the hit rate for the content retrieval. One future work could be to improve the interest packet coverage and reduce the duplicate packet. Inspired from the Multipoint Relay [16] in OLSR protocol, we may consider the Multipoint Relay scheme to direct the packet forwarding to further improve the coverage of the interest packet.

The experiment results show that the proposed content retrieval scheme in mobile cloud application reduces the total cost of the traffic overhead compared to the current probabilistic forwarding scheme and naive flooding scheme, and prunes a number of duplicate copies of the Interest with a high hit rate to retrieve the content successfully.

7. REFERENCES

[1] V. Jacobson, M. Mosko, D. Smetters, and J. Garcia-Luna-Aceves, "Content-centric networking," Whitepaper, Palo Alto Research Center, pp. 2-4, 2007.

[2] L. Zhang, D. Estrin, J. Burke, V. Jacobson, J. D. Thornton, D. K. Smetters, et al., "Named data networking (ndn) project," Relatório Técnico NDN-0001, Xerox Palo Alto Research Center-PARC, 2010.

[3] L. Wang, A. Afanasyev, R. Kuntz, R. Vuyyuru, R. Wakikawa, and L. Zhang, "Rapid traffic information dissemination using named data," presented at the Proceedings of the 1st ACM workshop on Emerging Name-Oriented Mobile Networking Design - Architecture, Algorithms, and Applications, Hilton Head, South Carolina, USA, 2012.

[4] S. Y. Oh, D. Lau, and M. Gerla, "Content centric networking in tactical and emergency manets," Wireless Days IFIP, pp. 1-5, 2010.

[5] M. Mariyasagayam, T. Osafune, and M. Lenardi, "Enhanced multi-hop vehicular broadcast (MHVB) for active safety applications," in Telecommunications, 2007. ITST'07. 7th International Conference on ITS, pp. 1-6, 2007.

[6] Lung-Chih Tung and M. Gerla, "An efficient road-based directional broadcast protocol for urban VANETs," in Vehicular Networking Conference (VNC), 2010 IEEE, 2010, pp. 9-16.

[7] E. Fasolo, A. Zanella, and M. Zorzi, "An effective broadcast scheme for alert message propagation in vehicular ad hoc networks," in Communications, 2006. ICC'06. IEEE International Conference on, pp. 3960-3965, 2006.

[8] M. Nekovee, "Epidemic algorithms for reliable and efficient information dissemination in vehicular," Intelligent Transport Systems, IET, vol. 3, pp. 104-110, 2009.

[9] M. Ripeanu and I. Foster, "Mapping the Gnutella Network: Macroscopic Properties of Large-Scale Peer-to-Peer Systems," in Peer-to-Peer Systems. vol. 2429, P. Druschel, F. Kaashoek, and A. Rowstron, Eds., ed: Springer Berlin Heidelberg, pp. 85-93, 2002.

[10] S. Saroiu, P. K. Gummadi, and S. D. Gribble, "Measurement study of peer-to-peer file sharing systems," pp. 156-170, 2001.

[11] N. Sarshar, P. O. Boykin, and V. P. Roychowdhury, "Percolation search in power law networks: making unstructured peer-to-peer networks scalable," in Peer-to-Peer Computing, 2004. Proceedings. Proceedings. Fourth International Conference on, pp. 2-9, 2004.

[12] C. Han and E. Do Young, "Crossing Over the Bounded Domain: From Exponential to Power-Law Intermeeting Time in Mobile Ad Hoc Networks," Networking, IEEE/ACM Transactions on, vol. 17, pp. 1578-1591, 2009.

[13] N. Sarshar, P. O. Boykin, and V. P. Roychowdhury, "Finite Percolation at a Multiple of the Threshold," arXiv preprint cond-mat/0601211, 2006.

[14] M. E. Newman, S. H. Strogatz, and D. J. Watts, "Random graphs with arbitrary degree distributions and their applications," Physical Review E, vol. 64, p. 026118, 2001.

[15] http://crawdad.cs.dartmouth.edu/meta.php?name=dartmouth/outdoor#N1000B.

[16] You Lu, Yenan Lin, Biao Zhou, Mario Gerla, "MPR-Aware Performance Improvement for Inter-Domain Routing in MANETs ", MILCOM 2011, Baltimore, MD, November. 2011.