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Multimedia Contents Caching Scheme in Mobile Ad-Hoc Network

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Abstract

In the mobile ad-hoc network (MANET), mobile nodes can freely move to anywhere whenever they want to. As MANET is no communication infrastructure, the route maintenance for transmitting the data and the volume of being transmitted data are important issues. In this paper, we adopt the content caching scheme to reduce the consumption of network bandwidth and node's battery power. The proposed caching scheme stores the data being delivered by a neighboring node located in 1 hop away from itself. This has resulted in the increases of the probability that a mobile node stores the data to be used in future request. In evaluation, we examined our proposed scheme in the view of the cache hit ratio as the function of the number of mobile nodes and 4 mobility models: random way point, random direction, boundless simulation area and Gaussian-Markov. From simulation results, we confirm that the proposed scheme offers better performance substantially.

Keywords: *Mobile ad-hoc network, caching, multimedia, streaming service*

1. Introduction

Mobile ad-hoc network (MANET) is a communication infrastructure-less network and mobile nodes can freely move to anywhere in the network whenever they want to. As there are no communication devices such as an access point and a base station, mobile nodes should connect to the other nodes by themselves without any help of public communication devices. Thus mobile nodes in MANET should establish and maintain the data delivery and the route maintenance.

If a mobile node wants to communicate with another one, the proper path should be established and maintained to support the robust data transmission. The routing protocols for MANET are split into two schemes: proactive and reactive [1-4].

Proactive routing protocols periodically exchange their own routing information to adjacent nodes [5, 6]. As each node can use the up-to-date routing information stored in its routing Table, the data transmission is immediately executed without the process to find a route for the destination node. These protocols can support various paths such as the shortest path and the maximum transmission bandwidth path, but have disadvantage of wasting the network bandwidth.

Reactive routing protocol can reduce the consumption of network bandwidth and the node's battery power as they generate the traffic in time of need only [7, 8]. The data transmission is executed after establishing the path between the request node and the

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destination node. Unlike proactive routing protocols, there are initial delays to send the data in reactive routing protocols.

The caching mechanism can reduce the consumption of network bandwidth and battery power as it use the data stored in mobile nodes [9]. Cooperating caching scheme shares and coordinate the data being stored in mobile nodes. The CacheData [10] scheme stores the data that is chosen by its popularity, *i.e.*, there were lots of requests for the data. Each mobile node executes the cache placement and replacement independently. The CachePath [10] scheme can support a path to be redirected to the cached node. Aggressive caching is the method that the same data is stored in only one mobile node selected in the specific area based on hop counts.

The ZoneCooperative [11] scheme finds the request data within mobile nodes Γ hops away from itself called zone. The request node first finds the data in its own cache. If not, it searches the data in its zone nodes. If cache hit in zone, as the requested data is sent from a node in zone not from the data server, the consumption of network bandwidth can be reduced. The bigger the value of Γ is, the longer the service latency is.

The NeighborCaching [12] scheme enhances the utilization of cache space. When its own cache is full, a not used data is copied to neighbor node that is in idle status while the data can be removed its own cache to secure the preservation space. If the removed data is needed again, the node requests the data to a neighbor node to keep the data. As a neighbor node is far away from itself due to the movement of mobile nodes, the request sends to the data server. If cache size is small, the data is frequently replaced and it may cause the consumption of network bandwidth.

This paper presents a contents data caching strategy to reduce the network traffic and the service latency. To establish and maintain the delivery tree, we adopt short distance vector algorithm based on the proactive and non-hierarchical topology routing protocol for MANET. All nodes on the delivery tree store and forward the streaming data. The adjacent node 1 hop away from the node transmitting the request data stores the by-passing data if its cache memory has enough space. Under the proposed scheme, both the transmitting node and the adjacent nodes store the data. We assume that the contents are consisted of blocks. The mobile node sends and stores the contents by block. As a mobile node need not store the whole contents, this method is useful in the environment to be frequently changed the network topology. A cache replacement policy is based on the popularity and block distance of the contents.

The remainder of the paper is organized as follows: Section 2 introduces the proposed caching scheme. Section 3 presents an analytic study of the proposed caching scheme. In section 4, we present the simulations and analysis of the results. Finally, we give out conclusion in section 5.

2. Proposed Contents Caching Schemes

In this section, we propose a hop-based data caching algorithm for mobile ad-hoc networks. This network has no fixed infrastructure for mobile communications. Mobile node can freely move to anywhere in the network. To communicate among mobile nodes, it is necessary to establish communication link between sender and receiver before sending data. As it can be easy to break communication link due to the movement of nodes, network topology is dynamic and temporary. The maintenance of the transmission route should be executed periodically or in time of need.

2.1. System Model

In this paper, we use tree based short distance routing protocol to deliver the requested data. Each node plays the parent node and the child node depending on the hierarchical location in the network topology. A node can have only one parent node but many child nodes more than one. This method does not support alternative route between sender and receiver but the burden of routing is less than the other methods such as proactive and reactive routing protocol.

(a) Time t (b) Time t + Δt

Figure 1. Mobile Ad-hoc Networks

Figure 1 shows part of mobile ad-hoc networks. There are 6 mobile nodes MNi{A, B, C, D, E, F} linked with each other under tree based routing protocol. Let MNB be data server that has contents of n items, C1, C2…, Cn. As shown in Figure 1(a), at time t, mobile node MNB has child nodes MNA, MNC and MND. MNF and MNE become child nodes of MND and MNB becomes the parent node of MND. When MNF requests an item Ci, the request packet is delivered to its parent node MND. And then MND forwards the request packet to its parent node MNB. As MNB has the requested item Ci, MNB starts to send Ci heading for the destination node MNF back to MND. At this time, mobile nodes MNA and MNC can receive the item Ci because they are child nodes of MNB. But these nodes do not forward the received item Ci as MNF is not their child node. With the same way, MND sends a received item Ci to MNF.

At time t + Δt, the network topology is changed due to the movement of nodes. MND is continuously served along the path MNB, MNA, MNC and MNF. Assume that mobile node MNE demands the same item Ci requested by MND at the previous time t. As MNB has only stored Ci, it can be served along the path MNB, MNA, MNC and MNF.

As mentioned above, in mobile ad-hoc networks, a request packet and a requested data is forwarded with hop-by-hop until they reach their final destination such as the data server or the mobile node requesting data. As the power of a mobile node is limited, it is an important issue to reduce the bandwidth consumption. So the number of hops between the data server and the request mobile node should be minimized.

2.2. Route Cache

In mobile ad-hoc networks, the requested data is forwarded with hop-by-hop from data server to the request mobile node. The intermediate mobile nodes on the delivery route of contents Ci know what kinds of data are transmitted and how much are they popular. In route cache, the intermediate mobile nodes caches passing-by contents Ci if they have enough free cache space.

Assume that a mobile node MNF requests a contents Ci at time t and routing is executed in every time Δt. So contents Ci is consisted of n blocks divided by Δt. Let Ci,b be contents where i is the contents identification and b is n’th block of contents. As shown in Figure 1(a), the first block of the requested contents Ci will be delivered along the route MNB, MND and MNF where MND is the intermediate node. MND and MNF cache the received data Ci, 0 where the size of cached data is [0, Δt]. At time t + Δt, as shown in Figure 1(b), the contents Ci is continuously served along the route MNB, MNA, MNC and MNF. MNA, MNC and MNF cache the received data Ci,1 where the size of cached data is [Δt, 2Δt].

With route cache scheme, before sending the request packet to data server, a mobile node first checks its own cache to verify the request contents have already stored. If cached, a mobile node does not send the request packet and serves the request contents to use the cached data. If not, a mobile node sends the request packet to data server and serves the contents received from the other node.

Assume that MNA, MNC, MND and MNE request the contents Ci at time t + Δt as shown in Figure 1(b). Mobile nodes MND and MNF has cached the first block of the contents Ci,0 where the size of cached data is [0, Δt]. As MND has already stored the contents Ci,0, it can locally offer the service without sending the request packet to the data server MNB. But as MNA, MNC and MNE have not stored it, they should send the request packet to data server MNB. In this case, two kinds of situations can be happened: the remote cache hit and the cache miss. The remote cache hit means that the request contents have been stored in more than one of the other mobile nodes. The distance between the requesting mobile node and the caching node is shorter than the distance between the requesting node and the data server.

The cases of MNE and MNC correspond to the remote cache hit. The request packet MNE is traveled toward the data server MNB and its forwarding route is MNF, MNC, MNA and MNB. When MNF received the request packet for the contents Ci,0, as this data has been already stored its own cache, MNF does not forward the request packet but sends its own cached data Ci,0 to MNE. MNC has two routes for the data Ci,0 : one is the route toward MNB and the other is MNF. Let D(i,j) be the distance from node i to j. D(C, B) is 3 and D(C, F) is 2. As the distance D(C, F) is shorter than D(C, B), MNC sends the request packet for Ci,0 to MNF and then manages the request by using the data received from MNF.

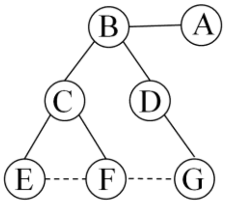
The cache miss means that the requested data item has not stored in the other nodes having shorter distance compared with the distance to the data server. The requested item is served by using received data from the data server. The cache miss cannot reduce the network bandwidth consumption.

In mobile ad-hoc networks, the process of delivering data is executed by storing and forwarding the received data fundamentally. As only mobile nodes participating in this process store the by-passing data, there is no extra power consumption to cache it.

2.3. Aggressive Cache

Aggressive cache scheme means that a mobile node not participating in the delivery process stores the data transmitted by the other nodes. Only a mobile node located in 1 hop away from the actual delivery nodes can execute aggressive caching scheme. In Figure 1(a) the nodes {MNB, MND, MNF} are participated in the delivery process. The nodes {MNA, MNC, MNE} does not engage in the process. A mobile node can communicate with the other nodes within the radio transmission range R. MNA and MNC are the child nodes of MNB. So MNA and MNC can receive the data transmitted by MNA. In the case that MNF requests the contents Ci,0 at time t, MNA and MNC receive the data Ci,0 transmitted by MNA. In Aggressive cache scheme, MNA and MNC cache the received data Ci,0 for future use. With the same way, MNE caches the received data Ci,0 transmitted by its parent node MND.

At time t + Δt, MNA, MNC, MND and MNE request the contents Ci,0. In route cache, MND can locally offer the service by using its own cached data. MNC and MNE can offer the service by using the data cached in the remote mobile node MNF. MNA cannot help using the data from the data server MNB. In aggressive cache, MNA, MNC, MND and MNE have stored the data Ci,0 at time t. The request for Ci,0 can be served locally by each mobile node itself without any communication to other nodes.



Contents Identification	Sequence Number	Local Cache	MN Id	Neighbor
C_i	1	0	D	0
C_i	1	0	G	1
C_i	2	0	D	0
C_i	2	1	F	0
C_i	3	1	F	0
		…..		

(a) Network Topology (b) Caching Table of Mobile Node F

Figure 2. Aggressive Caching Scheme

Figure 2 shows the example of aggressive caching scheme. There are 7 mobile nodes MNi{A, B, C, D, E, F, G} linked with each other under tree based routing protocol. This scheme uses the data cached in the nodes within 2 hops away from the request node. Let MNA be the data server which has contents Ci. The nodes are connected with other nodes as shown in Figure 2(a). Mobile node MNE can communicate with MNC and MNF as they are in transmission range R. MNC is the parent node of MNE. MNF is a neighbor node of MNE. Assume that MNE requests the first block of contents i, Ci,0 where Ci,0 is stored in MNA and MNG. MNF receiving this request packet surveys its own caching table to serve the request data if it has cached.

Figure 2(b) shows the caching table of mobile node MNF. Caching table is consisted of 5 elements: contents identification, sequence number, local cache, mobile node identification and neighbor. Local cache is 1 bit flag and means whether the data is in its own cache. Neighbor is 1 bit flag and means whether the mobile node is directly connected. From caching table, MNF knows that the request data Ci,0 is not stored in its own cache but stored in the cache of MNG. As MNF is the neighbor node of MNE, the distance to data server D(F, A) is equal to the distance D(E, A). The distance D(E, A) is 4 and D(E, A) is 3. To choose shorter path, MNF sends the request packet to MNG. MNG sends Ci,0 to MNF and then MNF sends it to MNE.

Due to the limited cache capacity, the stored data should be deleted. For this, we adopt the cache replacement policy based on the popularity and block distance of the contents. The popularity is measured by the access frequency of the contents. The block distance is offset value how long a block is far from the starting point of the contents. If cached data have the same popularity, the cached data with the highest block distance is selected as a victim.

3. Analytical Study

In above discussion, we proposed two caching: route cache and aggressive cache. In route cache scheme, only nodes in the delivery tree cache the data. The probability of a node caching the content c is Pc where c is the contents identification. The probability of serving the data from the nodes in delivery tree, Ps, is

$$P_S = \sum_{k=1}^{D_S-1} (1-P_c)^{k-1} P_c \tag{1}$$

where DS is the distance from a mobile node i to the contents server S and indicates the number of hops. The mean number of the forwarding data is calculated by the product of PS and Dj in each node where j is the node cached the requested data.

$$\overline{F_S} = \sum_{k=1}^{D_j} (1-P_c)^{k-1} P_c (D_k - 1) \tag{2}$$

Aggressive caching scheme uses the data cached in mobile nodes within 2 hops away from the request node. Let PA be the probability that a data is in the cache with aggressive cache scheme. The probability of the request data being stored in its own cache is Pa. The probability of the data being stored in its neighboring nodes is (1-Pa)Pa. The probability of the data being stored in the neighboring nodes of the neighboring nodes is (1-Pa)2Pa. Thus using the aggressive cache scheme, the probability of serving the data from the aggressive caching nodes, PA, is

$$P_A = \sum_{k=1}^{D_S-2} \sum_{i=1}^{3} (1-P_a)^{i-1} P_a \tag{3}$$

From equation (3), the mean number of the forwarding data in aggressive caching scheme is

$$\overline{F_A} = \sum_{k=1}^{D_j} (1-P_a)^{k-1} P_a (D_k - 1) \tag{4}$$

Equation (5) shows the amount of the reduced data Bsave with route cache scheme where Vc is the transmission rate to deliver the contents C. As the contents C is consisted of n blocks and each block is transmitted in the predefined time interval Δt when the routing technique is executed, the total amount of the saved data Btotal_save is shown in equation (6)

$$B_{save} = V_c (D_s - \overline{F}) \tag{5}$$

$$B_{total\_save} = \left\lceil \sum_{i=1}^{n} V_c (D_s - \overline{F}) \right\rceil \tag{6}$$

4. Simulation and Analysis

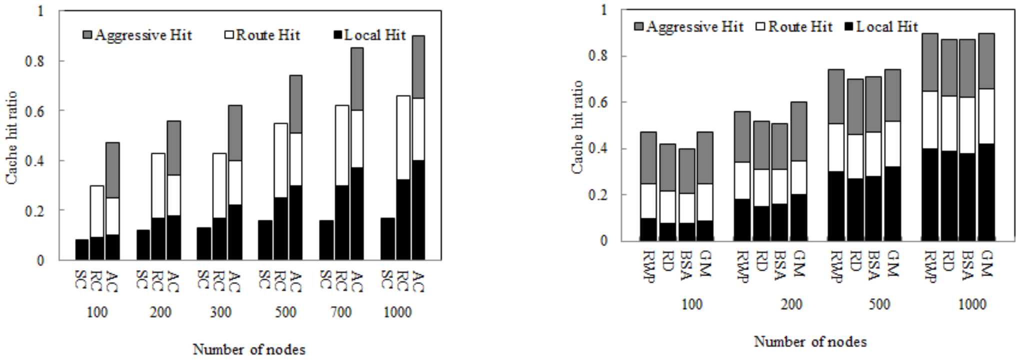
In this section, we show simulation results to demonstrate the benefit of proposed caching scheme in mobile ad-hoc network and analyze the results of performance using it.

Simulation parameters are listed in Table 1. The second column indicates the default values of these parameters. We also vary some of these parameters to do sensitivity analysis. The ranges of values used for simulation are given in the third column under the Range. The size of simulation network is varied from 100m × 1,000m to 1,000m × 1,000m in rectangular plan. The contents are consisted of 100 blocks where the size of each block is 50 KB. The access pattern of mobile nodes is depended on cut-off Zipf-like distribution with skew factor 0.8 [13].

Table 1. Simulation Parameters

Parameter	Default	Range	Unit
Contents	100	-	
Block	100	-	
Block size	50	-	K Bytes
Cache size	5	-	M Bytes
Request rate	1	-	Requests/minute
Bandwidth	10	-	M bits/second
Network area	500,000	100,000 ~ 1,000,000	meter^2
Node density	500	100 ~ 1000	meter^2/node
Transmission range	100	50 ~ 150	meter

We assume that all nodes can communicate to any other nodes in the network. To support the fully connection among mobile nodes, we make a simulation model satisfying the condition mentioned in [14]. The mobile nodes are distributed by Poisson random process. The node can freely and randomly move to anywhere in the network. To define node's mobility, we use 4 mobility models: random waypoint (RWP), random direction (RD), boundless simulation area (BSA) and Gaussian-Markov (GM) [15]. The node velocity is randomly selected from [0 m/s, 10 m/s] in all models. The angle is [0, 2π] for RWP and GM, and [0, π] for RD. In BSA, the maximum acceleration value is 10 m/s2, variable is π/2 and time variable is 1 second. In GM, variable is 0.75, mean is 0, standard deviation is 1 and bound is 10m.

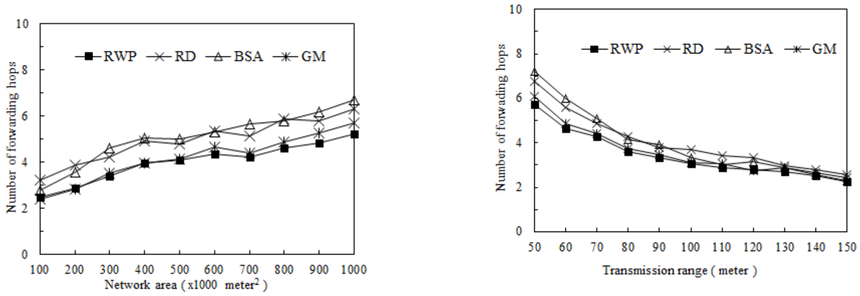


(a) Cache hit ratio (b) Cache hit ratio in various mobility

Figure 3. Simulation Results as the Function of the Number of Mobile Nodes

Figure 3(a) shows the cache hit ratio according to cache schemes such as simple cache (SC), route cache (RC) and aggressive cache (AC), in the view of the number of mobile nodes, where the network size is 100m × 1,000m, transmission range is 100m and the mobility model is RWP. Initially each node contains contents selected randomly. The number of requester is 50. The X-axis shows the number of mobile nodes while the Y-axis shows the total cache hit ratio stacked by local hit, route hit and aggressive hit. From the simulation result, the more the number of mobile nodes is, the higher the total cache hit ratio is. In aggressive caching scheme, the nodes 1 hop away from nodes on delivering tree store the data transmitted from them. As a result, it increases the probability of the necessary data stored in its own cache.

Figure 3(b) shows the cache hit ratio in the view of the number of mobile nodes and various mobility, where the network size is 500m × 1,000m, transmission range is 100m and the node density is 500m^2/node. The mobility of RD and BSA tends to move outer the network while RWP and GM to the network center. Thus RWP and GM have a higher chance of being located nearby the node transmitting the requested contents than that of RD and BSA. RWP and GM have a similar cache hit ratio due to their mobility properties. RWP and GM also have a similar cache hit ratio for the same reason. Simulation results show that the increase of the number of mobile nodes has resulted in increasing the cache hit ratio. The more the number of mobile nodes is, the less the difference of cache hit ratio among mobility is.



(a) Network Area

(b) Transmission Range

Figure 4. The Number of Forwarding Hops as the Function of the Network Area and the Transmission Range

Figure 4(a) shows the variation in the number of forwarding hop count as the function of the various network size ranged from 100,000m^2 to 1,000,000m^2 under the proposed scheme, where the node density is 500m^2/node and transmission range is 100m. The X-axis shows the network size while the Y-axis shows the number of forwarding hops. This value means the distance between the cached node and the request node and has value of hop counts - 1. The numbers of forwarding hops of RWP and GM is less than those of RD and BSA. As the same reason in Figure 3(b), RWP and GM has shorter path than RD and BSA.

Figure 4(b) shows the variation in the number of forwarding hop count as the function of the various transmission ranges varied from 100m to 1,000m under the aggressive caching scheme, where the network size is 500m x 1,000m and the node density is 500m^2/node. Therefore the number of forwarding hop counts is inversely proportional to the transition range.

5. Conclusion

In this paper, we proposed a caching scheme to reduce the consumption of the network bandwidth and node’s battery power. The proposed caching scheme stores the data being delivered by a neighboring node located in 1 hop away from itself. This has resulted in the increases of the probability that a mobile node stores the data to be used in future request. Due to the limitation of cache capacity, the cached data can be removed or replaced the new one based on the popularity and block distance of the contents. With this process, each node knows what kinds of contents and what parts of contents do the neighboring nodes store. The proposed scheme can use the data cached in the nodes within 2 hops away from a node related to the delivery process. To find the requested data, the nodes included in the routing process and the neighboring nodes search their own caching table to determine whether its neighboring nodes store the requested data. If a neighboring node stores the requested data, the request can be served between the request node and the neighboring node not the content server. The proposed scheme does not try to cache the whole contents on an identical item but try to cache a block unit of item. Thus it can reduce the load of a caching node and the heavier traffic near a caching node. In evaluation, we examined our proposed scheme in the view of the cache hit ratio as the function of the number of mobile nodes and 4 mobility models. The simulation results show that the cache hit ratios have almost the same value regardless of the mobility models. As increasing the number of mobile nodes make the total caching capacity of the network grow, cache hit ratio increases in the proportion of the number of nodes. Thus the caching capacity is the critical performance factor in order to minimize the consumption of the network bandwidth and node's battery power.

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