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Location and Direction Aware Priority Routing for Delay Tolerant Networks

조선대학교 일반대학원

컴퓨터공학 전공

심 검

지연 허용 네트워크에서 위치와 방향을 고려한 우선순위 라우팅

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지도교수 정 일 용

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ABSTRACT

Location and Direction Aware Priority Routing for Delay Tolerant Networks

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Delay Tolerant Networks (DTNs) are a class of emerging networks that experience frequent and long-duration partitions. Delay is inevitable in DTNs, thus, ensuring the validity and integrity of the message and making better use of buffer space are more important than concentrating on how to decrease the delay. In this paper, we present a routing protocol named *Location and Direction Aware Priority Routing* (*LDPR*) for DTNs, which utilizes the location and moving direction of nodes to deliver a message from source to destination. A node can get the location and moving direction of other nodes by receiving beacon packets periodically from anchor nodes and referring to *received signal strength indicator* (*RSSI*) for the beacon. LDPR contains two schemes named *transmission scheme* and *drop scheme*, which take advantages of the nodes' information of the location and moving direction to transmit the message and store the message into buffer space, respectively. Each message, in addition, is branded a certain priority according to the message's attributes (e.g. importance, validity, security and so on). The priority decides the transmission order when delivering message and the dropping sequence when the buffer is full. Simulation results show that the proposed LDPR outperforms the conventional protocols in terms of packet delivery ratio and routing overhead. In particular, LDPR is able to guarantee the validity and integrity of the message. We expect LDPR to be of greater value than other existing solutions in highly disconnected and mobile networks.

1. Introduction

DTNs are a practical class of emerging networks, which are an occasionally connected network comprised of one or more protocol families and experience frequent and long-duration partitions as well as long delay. Because there is no guarantee of end-to-end connectivity in DTNs, the routing protocols which have good performance in the conventional networks are not suitable for DTNs, which are characterized by latency, bandwidth limitations, error probability, node longevity, or path stability [1]. Applications of DTNs include wireless sensor networks, terrestrial wireless networks, satellite networks, underwater acoustic networks, and other military communications.

The simplest solution to the DTN routing problem is brute-force unconstrained replication or Epidemic Routing [2]. A number of ideas have been explored to improve the efficiency of Epidemic Routing, including Prioritized Epidemic Routing for Opportunistic Networks [3] and Probabilistic Routing in Intermittently Connected Networks [4]. The use of network topology to estimate the transmission path and to increase the efficiency of routing has been studied in [5, 6].

In general, routing protocols in DTNs are classified into two categories based on which property is used to find the destination: *flooding* families and *forwarding* families. To find the destination, two different approaches of *replication* and *knowledge* are used. The replication is used in the flooding strategy in which different algorithms can be used to make multiple copies of a message and to manage those copies. The knowledge is used in the forwarding strategy in which different approaches can be used to obtain some network state information and then to use it for making routing decisions [6].

Delay is inevitable in DTNs, thus, ensuring the validity and integrity of the message and making better use of buffer space is more important than concentrating on how to decrease the delay. In this paper, we present a novel routing protocol for DTNs called *Location and Direction Aware Priority Routing* (*LDPR*). Just as the name implies, LDPR utilizes the location and moving direction information of nodes to deliver a message from source to destination. A node can get the location and moving direction of other nodes by receiving beacon packets periodically from anchor nodes and referring to *received signal strength indicator* (*RSSI*) [15] for the beacon. Two schemes, named transmission scheme and drop scheme, take advantages of the nodes' information of the location and moving direction in transmitting the message and in storing the message into buffer space, respectively. Each message, in addition, is branded a certain priority according to the message's attributes (e.g. importance, validity, security and so on). The priority decides the transmission order when delivering message and the dropping sequence when the buffer is full.

Compared with other proposed routing protocols in DTNs, the most distinguished difference in LDPR is that some anchor nodes are deployed in a certain area to determine the location and moving direction information of the nodes by using RSSI. By this way, we can easily and accurately deliver the message from the source to the destination without completely depending on the message replication or thinking over the network topology information. Obviously, LDPR belongs neither to the flooding family nor to the forwarding family. All the routing protocols in DTNs have the common objective of trying to increase the delivery ratio while decreasing the resource consumption and latency. In this paper, LDPR can satisfy the requirement of the delivery ratio as much as possible and can make better use of buffer space. As is known to all, *buffer space*, *reliability* and *resource* *consumption* are important issues in routing protocols in DTNs. However, the disadvantage of this routing protocol is that LDPR lacks of scalability for a large network and needs lots of computation and cost. Our future work is to overcome these problems to design a more robust routing protocol for harsh operational environments.

The rest of this paper is organized as follows. In the following section, the related work on the delay tolerant routing protocols is briefly discussed. Location and Direction Aware Priority Routing Protocol is described in detail in Section 3. The simulation and result are presented in Section 4. Finally, the conclusions of this paper are covered in Section 5.

2. Related Work

Delay tolerant networks are a kind of application of Mobile Ad Hoc Networks (MANETs). The connection between the nodes, in DTNs, is intermittent and unstable because of node mobility. Some traditional routing protocols performed very well in Ad hoc networks may not perform well for DTNs, such as DSDV [7], DSR [8], and AODV [9]. Some researchers have paid lots of efforts on designing new protocols in this special field. In general, the routing protocols in DTNs are classified into two categories based on which property is used to find the destination: flooding families and forwarding families. To find the destination, two different approaches of replication and knowledge are used. The replication is used in the flooding strategy and there are many algorithms to manage multiple copies of a message and to make those copies. The knowledge is used in the forwarding strategy. Some works have been devoted to derive more efficient methods to obtain some network state information and then to use it to make routing decisions [6, 10]. One of the earliest proposals for routing in delay tolerant networks is epidemic routing [2]. In epidemic routing, all the nodes can become the carrier, and it is ensured that messages can be delivered with a high probability. Moreover, a number of ideas have been explored to improve the efficiency of Epidemic Routing, including Prioritized Epidemic Routing [3] and Probabilistic Routing [4]. The key idea about prioritized epidemic routing is to impose a partial ordering on the message called bundles. In probabilistic routing, when a message arrives at a node which does not have an available contact with other node, it must be stored in the buffer until the node encounters with another node. We should set a probability threshold on the nodes. It only admits that a node can receive the message when its delivery probability exceeds the threshold.

In addition, the use of network topology to estimate the transmission path and to increase the efficiency of routing has been studied in [5, 6]. Such as Source Routing, Per-Hop Routing, Per-Contact Routing and Hierarchical Routing, they all utilize the network topology information to effectively select the best path, and the message is then forwarded from node to node along with the path. The nodes typically send a single message along with the best path, so they do not use replication.

2.1 Traditional Routing Protocols in MANETs

This section briefly overviews the basic and typical routing protocols in mobile ad hoc networks, which are DSDV, DSR, and AODV, respectively.

Destination-Sequenced Distance-Vector (DSDV) [7] protocol is a proactive hop-by-hop distance vector routing protocol, which requires each MH (Mobile Host) to broadcast routing updates periodically. At the mean time, every MH maintains a routing table for all possible destinations and the number of hops to each destination. The sequence numbers enable the MHs to distinguish stale routes from new ones.

Dynamic Source Routing (DSR) [8] belongs to on-demand routing protocol. The source must know all the intermediate nodes to be traversed from the source to a destination, and they are included in the header of the packet to send.

Ad Hoc On-Demand Distance Vector Routing (AODV) [9] is an improvement on DSDV. It minimizes the number of required broadcasts by creating routes on demand basis. Basically, AODV is a combination of DSDV and DSR. It borrows the basic on-demand mechanism of route discovery and maintenance from DSR, plus the use of hop-by-hop routing, sequence number and periodic beacons from DSDV. Additionally, nodes that are not in a selected path do not maintain routing information or participate in routing table exchanges.

2.2 Epidemic Routing

One of the earliest proposals for routing in delay tolerant networks is epidemic routing [2]. Epidemic Routing, as the name suggests, likes the pattern of pandemic virus transmitting. In DTNs, all of the node can become the carrier, which can take the message from one node to another. In this way, messages are quickly distributed through the networks due to the random mobility. Of course Epidemic Routing relies upon carriers coming into contact with another node in the network by node mobility. We assume that: (i) the sender does not know where the receiver is currently located or the best "route" to follow, (ii) the receiver may also be a roaming wireless host, and (iii) pairs of hosts (not necessarily the sender and receiver) periodically and randomly come into communication range of one another through node mobility [2].

Using Epidemic Routing messages can be ensured that they have a high probability of the transmitting. Meanwhile the resource of network is consumed heavily. For solving this problem as much as possible, the objective of Epidemic Routing is to maximize the delivery rate, while minimize the transmit latency and the consumption of the resources.

For explicitly explaining the process of Epidemic Routing, we give an example as depicted in Figure 1.

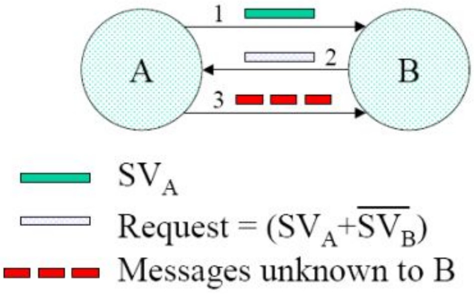


Figure 1. The process of epidemic routing protocol

When host A comes into transmission range of host B, an anti-entropy session is initiated. In the first step, A transmits it summary vector (called SV_A) to B, SV_A is a compact representation of all the messages which are buffered at A. Next, B performs a logical AND operation between the negation of its summary vector (given a symbol like $\neg SV_B$) and SV_A. We can easily get the conclusion the negation of B's summary vector representing the messages that it has never been seen. It implies, B finds the different vector, which B wants to need, compared with A's summary vector. And then transmits a vector requesting these messages from A. In the third step, A transmits the messages to B which are requested by B. This process is repeated transitively when B comes into contact with a new neighbor. Given sufficient buffer space and time, these anti-entropy sessions guarantee the message can be eventually delivered to the destination.

The critical resource in epidemic routing is the buffer. An intelligent buffer management scheme can improve the delivery ratio over the simple FIFO scheme. The best buffer policy evaluated is to drop packets that are the least likely to be delivered based on previous history. If node A has met B frequently, and B has met C frequently, then A is likely to deliver messages to C through B. Similar metrics are used in a number of epidemic protocol variants [4]. This approach takes advantage of physical locality and the fact that movement is not completely random. However, these protocols still transmit many copies of each message, making them very expensive.

2.3 Flooding Family Routing Protocols in DTNs

In the *flooding* families, each node has a number of copies of each message and transmits them to a set of nodes (sometimes called relays). All the relays maintain the copies and store them in their buffer space until they connect with the next nodes. The earliest works in the area of DTN routing fall into this family. Using the message replication can increase the probability of message delivery. The basic protocols in this family do not need any information about the network. However, if some knowledge of the network is referred to as an additional routing metric, the flooding strategy can be significantly improved. Direct contact [6, 10], two-hop relay [6, 10], tree-based flooding [6, 10], epidemic routing [2], prioritized epidemic routing [3], probabilistic routing [4], and reconfigurable ubiquitous networked embedded systems (RUNES) routing protocols belong to the flooding family [10].

We evaluated the flooding families in terms of various characteristics including important performance metrics. Hop count, the number of copies, resource usage, delivery ratio, routing vector/table, multipath support, effectiveness, and latency are studied in the comparative analysis. Table 1 summarizes the comparison results of the flooding families.

Table 1. Comparison of the flooding families.

	Hop count	Number of copies	Resource usage	Delivery ratio	Routing vector/table	Multipath support	Effectiveness	Latency
Direct contact	1	No	Low	Min	No	No	Bad	Long
Two-hop relay	2	n(1)	Low	Low	No	Yes	Bad	Long
Tree-based flooding	Many	$\sum_{i=0}^{n}\sum_{a=1}^{k} Ma$ (2)	High	Low	No	Yes	Bad	Long
Epidemic routing	Many	Unlimited	Max	Max	Yes	Yes	Normal	Long
Prioritized epidemic routing	Many	Limited	Limited	Normal	Yes	Yes	Good	Normal
Probabilistic routing	Many	Limited	Limited	Normal	Yes	No	Good	Normal
RUNES	Many	Limited	Limited	Normal	Yes	Maybe	Good	Long

(1) "n" is the number of the nodes in a network.

(2) "n" is the depth of a routing tree, "k" is the number of nodes at the same depth, and "Ma" is the number of copies of a message in node a.

From the comparison Table 1, some conclusive comments can be inferred: The prioritized epidemic routing is the best of the flooding families even though it has some drawbacks such as poor resource usage.

2.4 Forwarding Family Routing Protocols in DTNs

In the *forwarding* families, the network topology information is effectively utilized to select the best path, and the message is then forwarded from node to node along with the path. Note that the routing protocols in this family require some knowledge about the network. The nodes typically send a single message along with the best path, so they do not use replication. Location-based routing [6, 10], source routing [6, 10], per-hop routing [13], per-contact routing [13], and hierarchical routing protocols [14] belong to the forwarding family.

We evaluated the forwarding families as well, where flexibility, resource consumption, information usage, routing vector/table, scalability, loop freedom, effectiveness, delivery ratio, and latency are studied and compared. Table 2 summarizes the comparison results of the forwarding families.

Table 2. Comparison of the forwarding families.

	Flexibility	Resource consumption	Information usage	Routing vector/table	Scalability	Loop-free	Effective-ness	Delivery ratio	Latency
Location based routing	Bad	Little	Little	No	Bad	Yes	Bad	Min	Normal
Source routing	Bad	Normal	Normal	No	Bad	Yes	Bad	Low	Long
Per-hop routing	Bad	Normal	Normal	No	Bad	Yes	Bad	Low	Long
Per-contact routing	Good	Many	Many	Yes	Bad	No	Normal	Normal	Normal
Hierarchical routing	Good	Many	Many	Yes	Good	Yes	Good	Max	Normal

From the comparison Table 2, the hierarchical routing can be primarily chosen thanks to its many outstanding features although it has two negative characteristics of poor information aggregation and information compression.

3. Location and Direction Aware Priority Routing Protocol

Before describing Location and Direction Aware Priority Routing Protocol (LDPR) in detail, we briefly present the key idea about LDPR. We make use of anchor nodes to estimate the location and moving direction information of the nodes. Depending on this information, we choose the best next hop to relay the message until the destination. During this process, priority is employed to decide which message should be delivered first among lots of messages wanted to be transferred. At the same time, when the buffer space in the relay node is full, priority is also taken advantage of to determine which message should be dropped or be transferred to other nodes having available buffer space.

For successfully delivering the message, first, network should be initialized. All the nodes are deployed in a given area. There are two kinds of nodes exist in the network. One is anchor node, the other is general node. General nodes all have the same radio transmission range and move randomly, while anchor nodes can determine the location and moving direction information of general nodes by using RSSI [15]. In order to preferably route data from source to destination, we pre-determine some properties about the anchor nodes:

- All the anchor nodes have enough energy and capability of storing.
- Radio transmission range of anchor nodes is large enough to cover the whole scale of the network.
- Location of anchor nodes can be exactly obtained by GPS or other assistant methods.
- All the anchor nodes can move randomly around the network.

General nodes obtain the location information by making use of RSSI technique. As we known, in RSSI, one general node wanted to estimate its location should at least connect with three anchor nodes so as to calculate the location by trilateration. Every node stores its own location and moving direction information. In order to minimizing the communication overhead, however, all the information will not be exchanged with each other unless they are required between the nodes. Moreover, when an anchor node is situated in the transmission range of a certain general node, the information of this general node can be stored in this anchor node. For simply description, we can also say that this anchor node lists this general node. After some time interval (period), yet, the anchor node should update its list so as to re-obtain the latest location and moving direction information of the general nodes, whose radio transmission range includes this anchor node.

In order to understand the information achieving operation of the LDPR protocol, consider the following scenario depicted in Figure 2. We assume that there is a message (data) wanted to be transmitted from the source node (S) to the destination node (D). If there is an anchor node in the transmission range of node S, S can request the anchor node to find the destination's location. Otherwise, node S will wait for sometimes until an anchor node appears in its transmission range. After this anchor node broadcasting the ID of the destination node, all the other anchor nodes will check their list to find destination node. If finding the destination node, the source can obtain the information about it. As shown in Figure 2, anchor node 1 is in the transmission range of nodes A, B and S. Hence, the location information of nodes A, B and S can be stored in this anchor node. We can also say anchor node 1 lists nodes A, B and S. In a similar way, anchor node 2 lists nodes F, D, H, and G. Therefore, source node S can request anchor node 1 to check its list or to broadcast the request to check other anchor nodes whether or not including the destination node D. Anchor node 2 transmits the location information to anchor node 1 after receiving the request and checking its list. Source node S, finally, obtains the location information about node D by relaying on anchor node 1. In the worst case, if there is no anchor node in the transmission range of destination node D, then D will wait for some time until it can be listed in a certain anchor node due to all the general nodes and the anchor nodes being mobile.

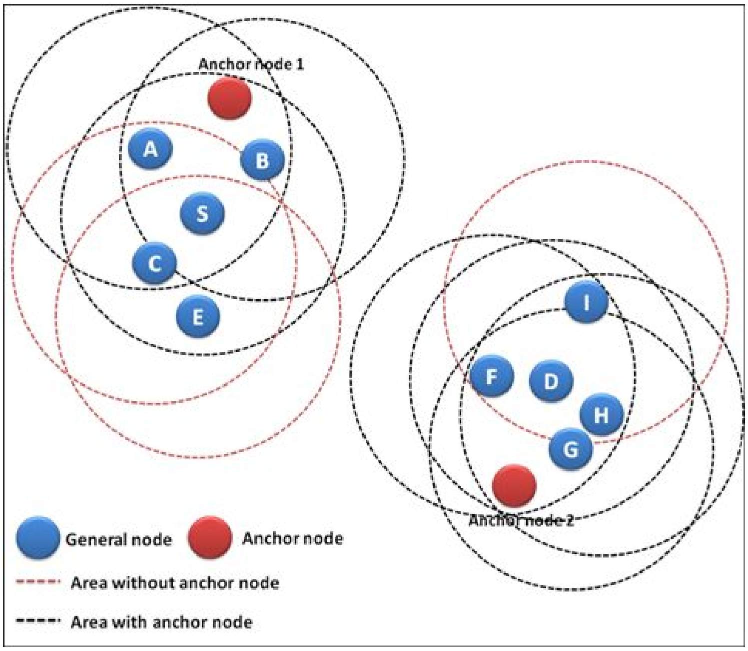


Figure 2. An example of achieving location information of destination node D

In LDPR, all of the messages wanted to be transferred must be attached with the priority information, which should be set based on the factors as follows:

- The validity of the message
- The security of the message
- Transmission speed request
- The value of information
- The cost of the message
- The distance to the destination and the direction to the destination.

The arranging sequence of these factors is abided by the priority level.

LDPR consists of two schemes: a transmission scheme that enables transmitting messages in compliance with their priority, and a drop scheme for managing and utilizing the buffer space. Each of these is described below.

3.1 Transmission Scheme

All the messages must be arranged in the buffer space of the nodes according to their priority. The message which has a highest priority will be arranged at the top level of the buffer space, at the same time, it will be first transmitted if the best next hop is determined.

When we transmit some messages from the source to the destination, at first, we should know all the information of the destination. Now we suppose that there is a message wanted to be transmitted from the source node (S) to the destination node (D), thus, the location and moving direction information of the destination node should be known first, and then they will be attached to the message. The process how to obtain this information is described above.

After node S getting the information of destination D, the second step is that determining the next hop for this transmission. In the beginning, node S broadcasts "destination location" request. As shown in Figure 3. If node D is in the range of the transmission range of S, then node D replies to S before node S directly transmitting the message to node D. Otherwise, if node D is not in this range, then no node replies to S. After that node S broadcasts the "moving direction" request. This situation is illustrated in Figure 4.

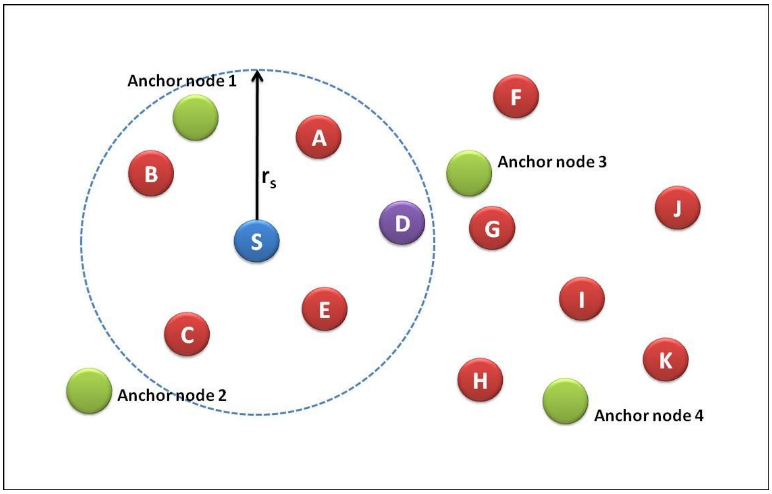


Figure 3. Node S broadcasts "destination location" request

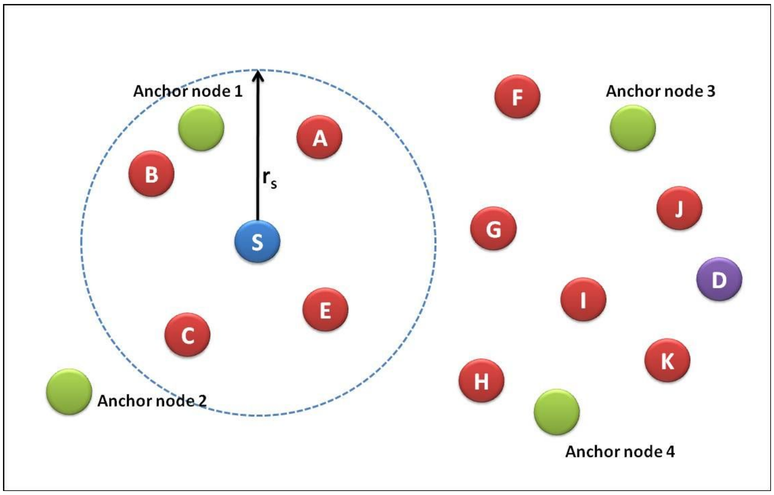


Figure 4. Node S broadcasts "moving direction" request

All the information of the nodes in the transmission range of node S are know by node S through directly communicating with these nodes after node S broadcasting "moving direction" request.

As shown in Figure 5, node A’s moving direction is same with the message’s transmission direction, hence, node A replies to node S and the message is delivered to node A immediately. That is to say, A becomes the best next hop. In another situation depicted in Figure 6, there are two nodes (A and C) both having the same moving direction with the message’s transmission direction, then the moving speed of node A and node C is compared with each other in order to determine which node should accept and relay the message. The node having higher speed can only become the next hop. Hence, node A replies to S before the message being transmitted to node A only if node A's speed is faster than node C's.

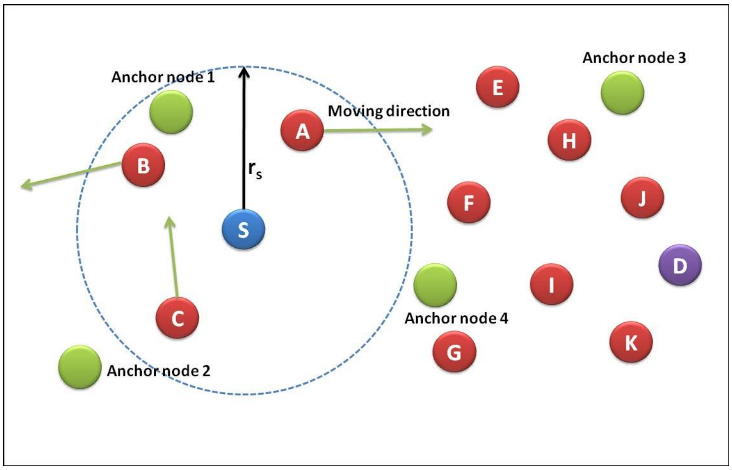


Figure 5. Node A’s moving direction is same to the message’s transmission direction

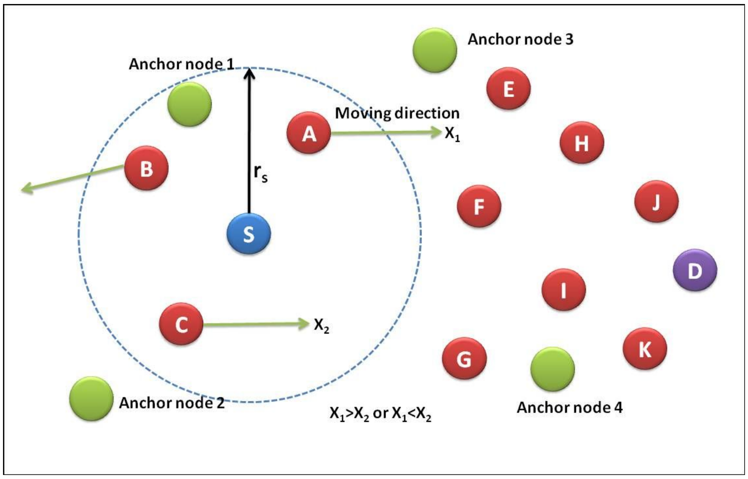


Figure 6. Nodes A and C both have the same moving direction with the message’s transmission direction

In the worst case, all the moving directions of the nodes in the transmission range of node S are different from the message's transmission direction, then no node replies to node S. Therefore, node S will wait. This scenario is explained in Figure 7.

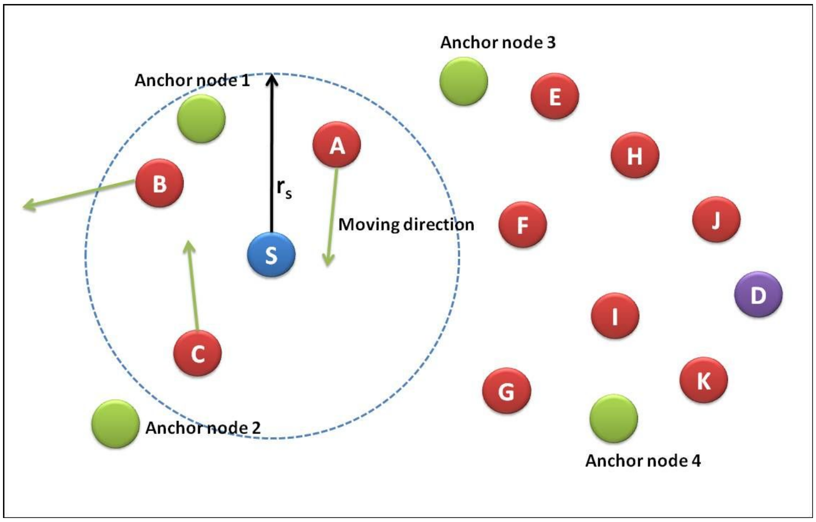


Figure 7. All the nodes in the transmission range of node S are different from the message's transmission direction

However, there exists one problem by using this transmission scheme, which is depicted in Figure 8. Even though all the nodes moving direction are different from the message's transmission direction, node E in the transmission range of node A has the same moving direction with the message direction information. In other words, the message may be delivered to the destination successfully if node S can deliver the message to node A.

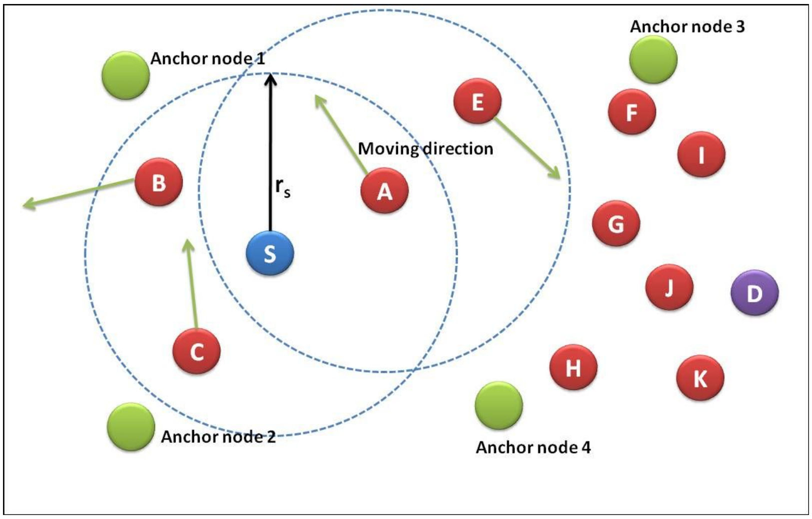


Figure 8. Node E's moving direction is same to the message's transmission direction

Finally, the best next hop is decided. Thus the message is delivered to and stored in this intermediate node, which continues to determine the next hop by this transmission scheme until the message successfully arriving at the destination node.

3.2 Drop Scheme

Once the source node determines the first next hop to the destination, it will transmit the message to the first intermediate node. However, the buffer space in this node is available or not? How can we to optimize the buffer space? In LDPR, the drop scheme solves these problems.

For explaining the drop scheme in detail, an explicit example is given in Figure 9. We assume that node S is the source and node D is the destination. Node A is supposed to be the best next hop determined by the transmission scheme described above. Nodes B, C, E, and F are in the transmission range of node A but not in the range of node S. There is a message which intends to be transmitted from node S to node A.

First, node S sends a "transmission" request to node A. After receiving the request, node A checks its buffer space to determine whether or not the buffer space is available. Node A replies to node S and permits the transmission only if node A’s buffer space is not full. Then node S sends the new message to node A. However, if node A’s buffer space is full, node A still replies to node S and only permits to accept the priority information of this message sent from node S. Then node A compares this priority information with others which have already stored in node A's buffer space.

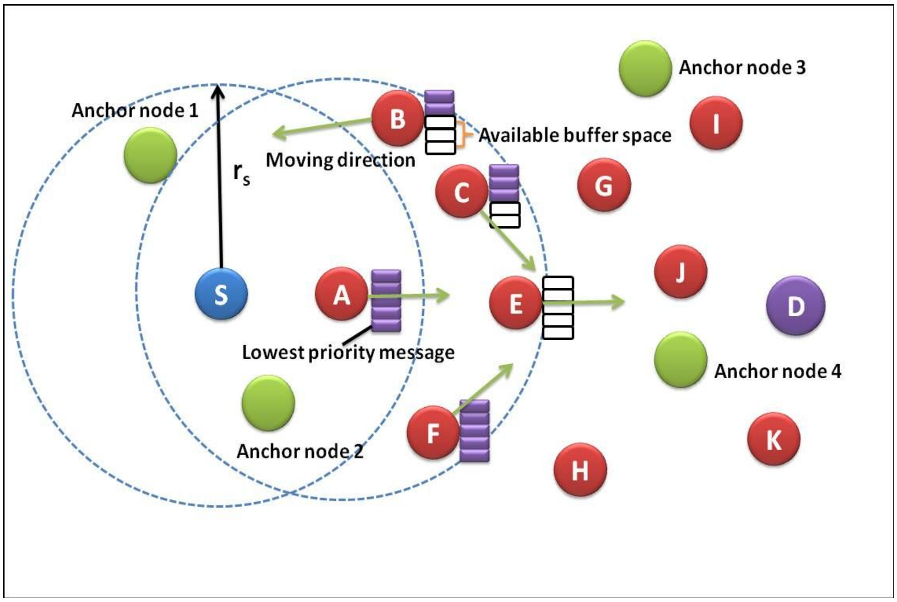
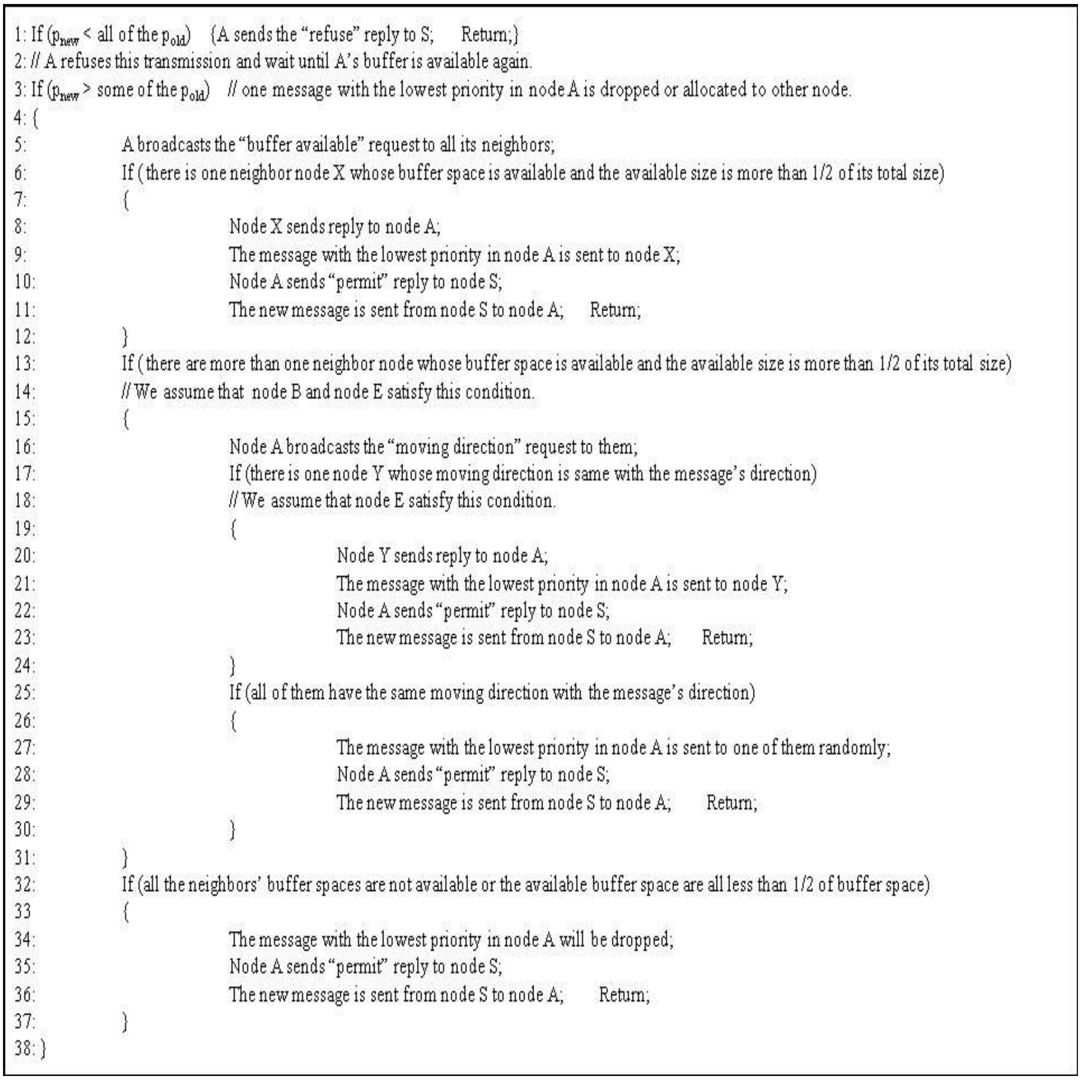


Figure 9. An example in drop scheme

Figure 10 explains the detailed steps of the priority comparing algorithm in drop scheme. Here, p_{new} represents the priority of the new message needed to be delivered to the destination, on the contrary, p_{old} delegates the priority of the old message stored in node A. If p_{new} is lower than all the p_{old}s, then node A will refuse this new message to be transmitted from node S to node A or permit it until node A's buffer is available again. In this condition, hence, node A sends the "refuse" reply to node S (Line 1-2 in Figure 10). However, if p_{new} is higher than some of p_{old}s, then one message with the lowest priority in node A will be dropped or be allocated to other available buffer space in other nodes in order to make space for storing this new message (Line 3). First, node A broadcasts the "buffer available" request to all its neighbors to do the judgment which node's buffer space is available. If there is one neighbor node whose buffer space is available and the available size is more than 1/2 of its total size. Then this node replies to node A and allows accepting the lowest priority message sent from node A. If so, the new message can be transferred from node S to node A successfully (Line 5-12). In our example according to Figure 9, we suppose that node B's buffer is available and the available size is more than 1/2 of its total size, while node C's buffer is also available, however C's available size is less than 1/2 of its total size. In addition, node E has an empty buffer space that can be available completely. To the contrary, node F's buffer is not available completely. Hence, nodes B and E reply to node A, while nodes F and C keep silent. This is easy to be explained because only node B or E having enough available buffer space can accept this lowest priority message. Secondly, node A broadcasts the "moving direction" request to nodes B and E. We assume that node B's moving direction is opposite with the message's direction while node E's is same. Therefore, indubitability, node E replies to node A and permits to accept the lowest priority message sent from node A. In this case, node A can make room for the new message from node S. Finally, node A replies to S and permits the new message to be delivered (Line 13-24). Of course, there exists another case. When node B and node E have the same moving direction with the message's direction, the message with the lowest priority in node A will be sent to one of them randomly (Line 25-31).

In the worst case, additionally, if all the neighbors' buffer spaces are not available or their available buffer spaces are all less than 1/2 of their buffer spaces respectively, then the message with the lowest priority in node A will be dropped so that node A can accept the new message (Line 32-37).

After the message successfully being transmitted from node S to node A, according to all the messages' priority, node A continues deciding the best next hop of the highest priority message until this message arriving at the destination by using the same transmission and drop scheme in LDPR as described above.



```
If ($p_{new}$ < all of the $p_{old}$)    {A sends the "refuse" reply to S;     Return;}
// A refuses this transmission and wait until A's buffer is available again.
If ($p_{new}$ > some of the $p_{old}$)    // one message with the lowest priority in node A is dropped or allocated to other node.
{
    A broadcasts the "buffer available" request to all its neighbors;
    If ( there is one neighbor node X whose buffer space is available and the available size is more than 1/2 of its total size)
    {
        Node X sends reply to node A;
        The message with the lowest priority in node A is sent to node X;
        Node A sends "permit" reply to node S;
        The new message is sent from node S to node A;     Return;
    }
    If ( there are more than one neighbor node whose buffer space is available and the available size is more than 1/2 of its total size)
    // We assume that node B and node E satisfy this condition.
    {
        Node A broadcasts the "moving direction" request to them;
        If (there is one node Y whose moving direction is same with the message's direction)
        // We assume that node E satisfy this condition.
        {
            Node Y sends reply to node A;
            The message with the lowest priority in node A is sent to node Y;
            Node A sends "permit" reply to node S;
            The new message is sent from node S to node A;     Return;
        }
        If (all of them have the same moving direction with the message's direction)
        {
            The message with the lowest priority in node A is sent to one of them randomly;
            Node A sends "permit" reply to node S;
            The new message is sent from node S to node A;     Return;
        }
    }
    If (all the neighbors' buffer spaces are not available or the available buffer space are all less than 1/2 of buffer space)
    {
        The message with the lowest priority in node A will be dropped;
        Node A sends "permit" reply to node S;
        The new message is sent from node S to node A;     Return;
    }
}
```

Figure 10. Priority comparing algorithm in drop scheme

4. Performance Evaluation

4.1 Simulation Environment

Table 3. Parameters used in the simulation

Parameter	Value
Number of node	50
Mobility model	Random way point
Mac	IEEE 802.11 DCF
Traffic source	CBR for UDP-based traffic
Node speed	0~5m/sec
Propagation model	Two-ray ground reflection
Simulation time	1000 seconds
Data transmission rate	2 Mbps
Radio transmission range	250m
Pause time	0, 20, 50, 100, 300, 600, 900 seconds
Packet outgoing rate	1, 2, 4, 8, 16 packets/sec
Number of Sessions	2, 6, 10, 14, 18

We implemented LDPR by using the ns-2 simulator. The version of ns-2 used in our simulation is ns-2.33. The implementation of our proposed routing protocol is based on the Monarch [11] extensions to ns-2. Monarch extends ns with radio propagation that models signal capture and collision. The simulator also models node mobility, allowing for experimentation with ad hoc routing protocols that must cope with frequently changing network topology. Finally, Monarch implements the IEEE 802.11 [12] Medium Access Control (MAC) protocol.

Unless otherwise noted, our simulations are run with the following parameters. We model 20, 50, 100 and 150 mobile nodes (including 10%anchor nodes) moving in a square area of 1000 m x 1000 m. Each node picks a random spot in the square and moves there with a speed uniformly distributed between 0~5 m/s. The radio transmission range is assumed to be 250 meters and a two-ray ground reflection propagation channel is assumed. The parameters for the simulation are given in Table 1. Most other parameters use ns-2 defaults. Nodes were generated randomly in an area and move according to the well-known Random waypoint mobility model.

Due to space restrictions, we have focused on comparing the performance of the protocols with regards to the following metrics. First of all, we are interested in the *packet delivery ratio*, i.e. how many of packets are delivered to the destination. The definition of *packet delivery ratio* is given in Eq.1.

$$Packet\ Delivery\ Ratio = \frac{Number\ of\ delivered\ packets}{Number\ of\ generated\ packets} \dots\dots\dots\dots\dots (1)$$

Even though the applications assumed in this study are relatively delay-tolerant, it is still of interest to consider the *end-to-end delay* of packet delivery to find out how much time it takes for a message to be delivered. The calculation of *end-to-end delay* is shown in

Eq.2.

$$\begin{aligned} Average\ end-to-end\ delay \\ &= average\ value\ of\ (delivered\ packet's\ timestamp \\ &- generated\ packet's\ timestamp) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2) \end{aligned}$$

Finally, we also study the *normalized routing overhead* of the whole network. This indicates the system resource utilization and consumption. The *normalized routing overhead* equation is described in Eq.3.

$$\begin{aligned} Normalized\ Routing\ Overhead \\ &= \frac{Number\ of\ routing\ packet\ transmission}{Number\ of\ data\ packet\ transmission} \ldots (3) \end{aligned}$$

We did simulations for each scenario. For measuring the three performance metrics, three simulation factors of the pause time, the packet outgoing rate (transmission rate), and the number of sessions are varied in a meaningful range (i.e., the pause time from 0 to 900s, the packet outgoing rate from 1 to 16packets/sec, and the number of sessions from 2 to 18 are applied). While one simulation factor is varied during a simulation, the others are fixed as follows: the pause time is 100s, the packet outgoing rate is 4packets/sec, and the number is sessions of 6.

4.2 Results and Discussion

Our simulation includes two parts. In the first part, we present a comparative simulation analysis of LDPR with AODV, DSDV and DSR with respect to packet delivery ratio, normalized routing overhead and average end-to-end delay. The number of nodes is set to be 50 and the buffer size of each node is assumed to be 50. In the second part, we only focus on reporting a comparative simulation result about packet delivery ratio of LDPR with respect to different nodes density and buffer size. The number of nodes is varied from 20 to 150 and the buffer size is considered from 10 to 1000.

4.2.1 Packet Delivery Ratio

The first interesting aspect that we analyze is the packet delivery ratio, a characterizing aspect of a protocol for delay tolerant networks. We investigate the delivery ratio of the protocols in the different scenarios, shown in Figs. 11, 12 and 13. It is easy to see that the pause time, transmission rate, and number of sessions impact performance.

As shown in Figure 11, as the pause time increasing, the packet delivery ratio increases generally. Look from whole, obviously, all the curves gradually raise up. This is intuitive, since a larger pause time means that nodes are more close to static and the networks are more stable. In particular, the packet delivery ratio of DSDV, DSR and AODV has a transient decrease when the pause time is 100s. It means that when a node reaches some certain location, it stays there during the pause time (100s) and then repeats the mobility behavior. The fact that the pause time is 0 implies the nodes are continuously moving. In this case, mobility can maintain the transmission between the nodes, even though the connection is always broken. However, when the pause time is 100s, the nodes stop for 100s. This pause time is not enough to establish a stable routing path and breaks down the mobility. It leads to the unstable path between each other. Hence, the curves of DSDV, DSR and AODV appear the sharply drop back. Additionally, the curve of LDPR shows that the packet delivery ratio persistently increases as the pause time rising up. Because LDPR periodically needs to estimate location and moving direction, the networks is closer to static state, the higher packet delivery ratio can be obtained. Compared packet delivery ratio with other three routing protocols, the performance of LDPR is the best. It always maintains a high packet delivery ratio under different pause time. Figure 12 describes the change of packet delivery ratio as the packet outgoing rate increasing. Intuitively, the packet delivery ratio, in a certain buffer size, will reduce as the packet outgoing rate raising. If the packet outgoing rate exceeds the maximum accommodation capability of buffer, it must lead to some packets drop during the transmission. As expected, the actual curves agree with the hypothesis mentioned above. And for each metric, LDPR still has the highest packet delivery ratio comparing with other routing protocols under various packet outgoing rates (packet transmission rates). As depicted in Figure 13, the packet delivery ratio gradually increases following the number of sessions increasing. The number of sessions defines the maximum number of connections between nodes. Similar to the former figures, LDPR has the best performance of packet delivery ratio in all cases of number of sessions.

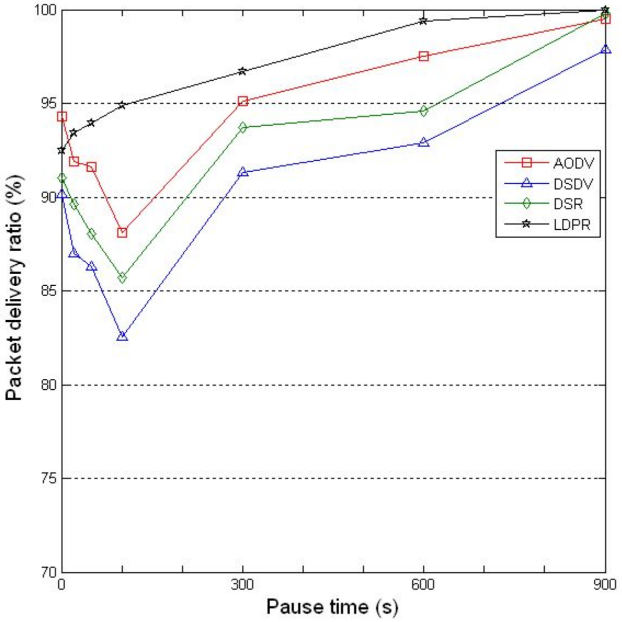


Figure 11. Packet delivery ratio versus pause time

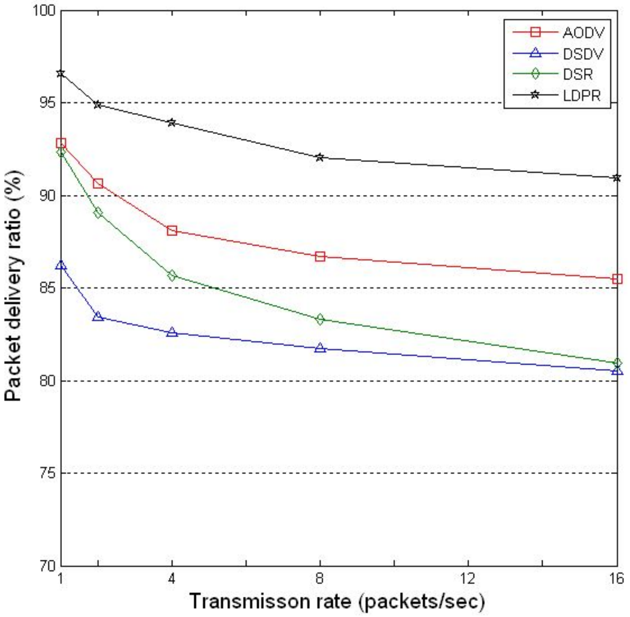


Figure 12. Packet delivery ratio versus transmission rate

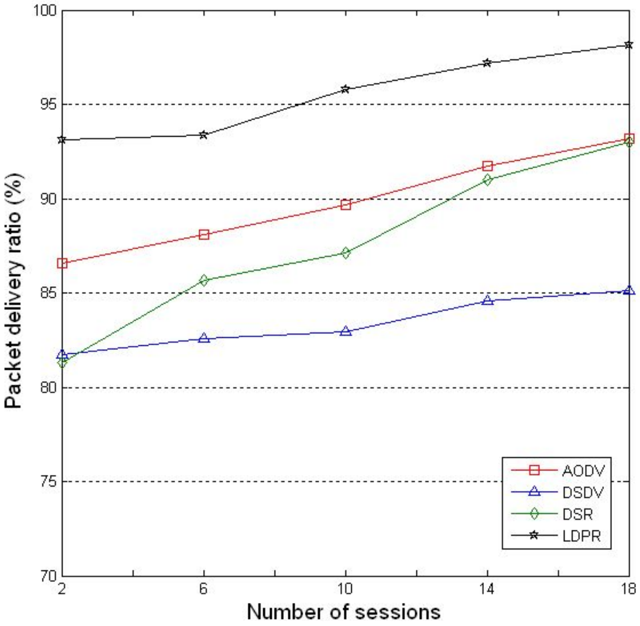


Figure 13. Packet delivery ratio versus number of sessions

4.2.2 Normalized Routing Overhead

Another critical aspect we investigated is the normalized routing overhead. Figs. 14, 15 and 16 show the impact of pause time, transmission rate and number of sessions on the normalized routing overhead. As we know, normalized routing overhead indicates the system resource utilization and consumption. It is an important criterion to estimate the performance of routing protocols. In these simulations, it is easy to tell that LDPR brings out lower routing overhead compared with other routing protocols and the curve of LDPR looks like more stable than other routing protocols'.

Figure 14 shows that the routing overhead decreases with the pause time increasing in all the routing protocols. In particular, the change of LDPR's curve is small. It indicates that the performance of LDPR is stable. Meanwhile, the routing overhead of LDPR is lower than AODV and DSDV when the pause time is less than 300s. Even though the pause time is more than 300s, the routing overhead of LDPR is almost same with AODV and DSR. Figure 15 represents that the routing overhead increases as the packet outgoing rate increasing. Nevertheless, seen from the shape of the LDPR's curve, the routing overhead of LDPR always maintains a low level. We note that the routing overhead of LDPR is lower than AODV and DSDV, and almost same with the DSR in most cases. In particular, the routing overhead of DSDV comes to 18 when the transmission rate is 16. In Figure 16, as expected, LDPR has lower routing overhead under different number of sessions. The shape of the LDPR's curve state that the routing overhead of LDPR is almost lower than AODV and DSDV in each case.

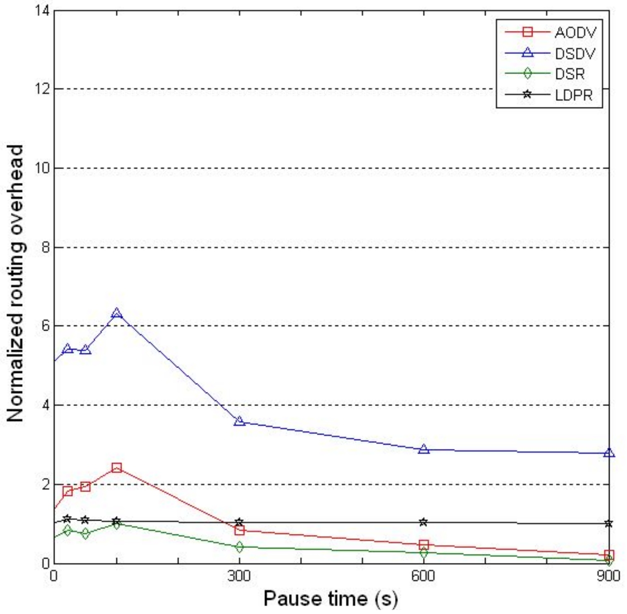


Figure 14. Normalized routing overhead versus pause time

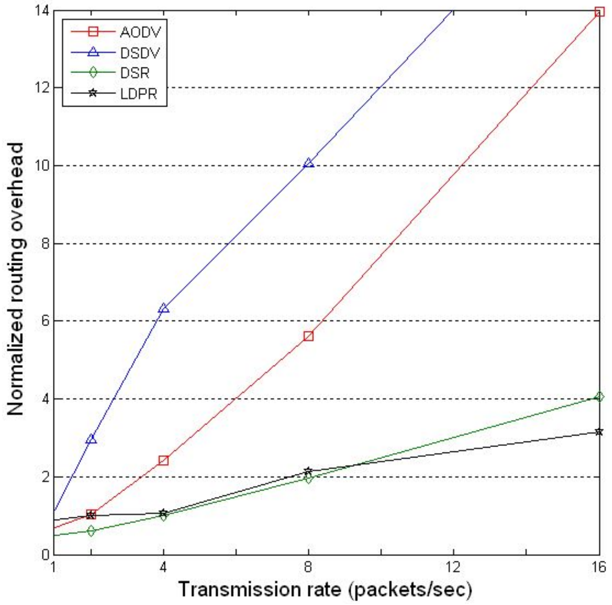


Figure 15. Normalized routing overhead versus transmission rate

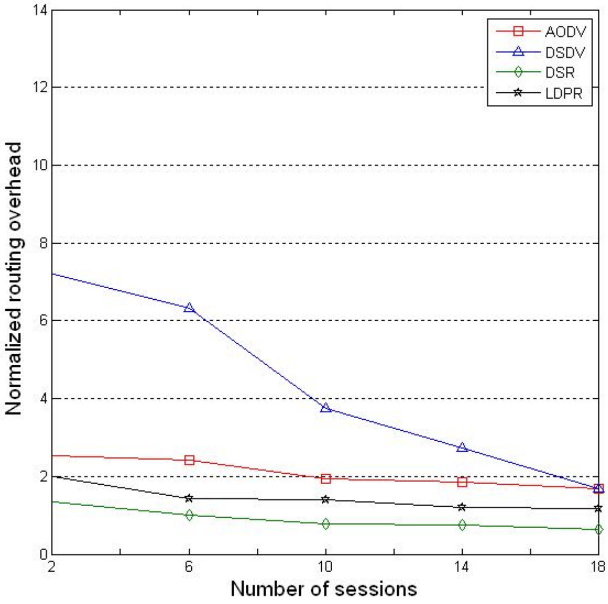


Figure 16. Normalized routing overhead versus number of session

4.2.3 Average End-to-End Delay

Delay is inevitable in DTNs, it is still of interest to consider the end-to-end delay to find out how much time it takes for a message to be delivered. In fact, it makes sense to compare with other routing protocols with regards to average end-to-end delay. In other words, it makes better reflection on the difference of delivery time in order to making better choice under the complicated environment and the real applications.

Let us observe the results related to the 50 nodes scenarios reported in Figs. 17, 18, and 19. Viewed from all of these figures, we note that the packet delivery delay of LDPR is longer than other three routing protocols in most cases in the condition of different pause time, various transmission rate, and distinct number of sessions. In particular, the end-to-end delay of LDPR reaches 182(ms) when the transmission rate is 16 packets/sec in Fig. 18. We note that, in LDPR, nodes are required enough time to obtain the information of location and moving direction. Moreover, all the nodes move randomly across this area. It dooms that the nodes need to usually gather and update the information in a certain time interval. In the meantime, the feature of packet delivery delay in LDPR determines that LDPR can be implemented in the environment which focuses on the validity and integrity of the message rather than delivery delay.

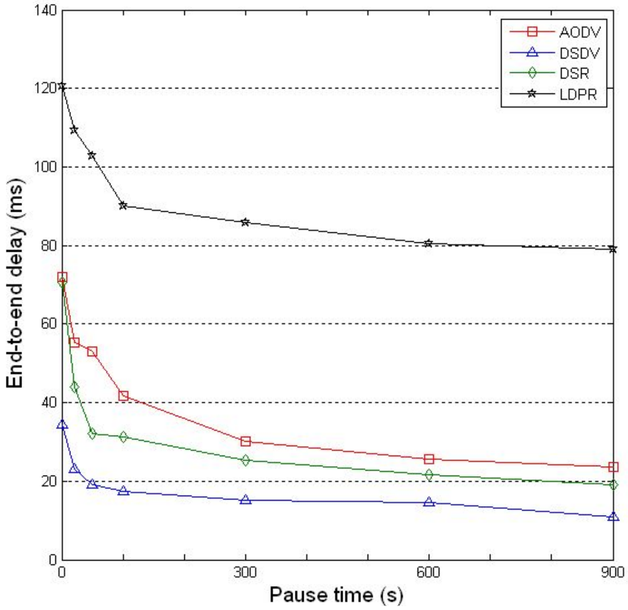


Figure 17. End-to-End delay versus pause time

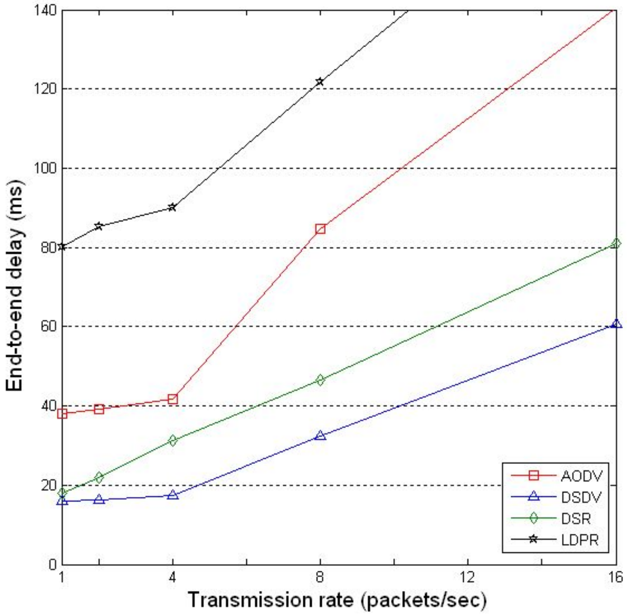


Figure 18. End-to-End delay versus transmission rate

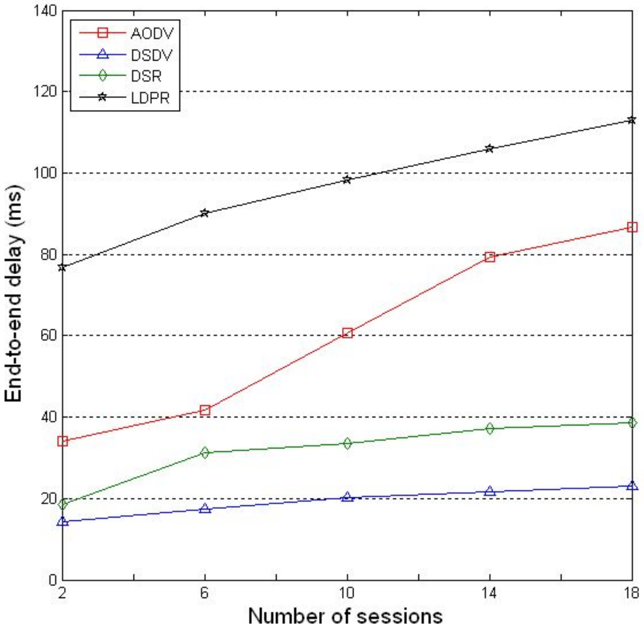


Figure 19. End-to-End delay versus number of session

4.2.4 Effect of Node Density

We now analyze the influence of the choice of the values of the nodes density. We consider four different numbers of nodes in the square 1000 m x 1000 m, where there are 20 nodes, 50 nodes, 100 nodes and 150 nodes, respectively. We still choose the parameters of X axis with respect to pause time, transmission rate and number of sessions. However, here, we only consider the packet delivery ratio as the parameter of Y axis. Figs. 20, 21, and 23 show the influence of the nodes density on the packet delivery ratio separately based on pause time, transmission rate, and number of sessions.

Viewed from Figure 20, we note that the packet delivery ratio gradually increases as the pause time increasing. The reason has been explained in simulation part one. The key point, here, is observing the influence of nodes density. In general, the higher nodes density leads to higher packet delivery ratio. In LDPR, for each metric, the packet delivery ratio is lower than other conditions when there are only 20 nodes in the area. In addition, the packet delivery ratio is highest when the number of nodes reaches to 50. However, if the nodes' number exceeds 50, the packet delivery ratio still maintains at a high level but decreases as the number of nodes increasing. That's because, in LDPR, all the nodes delivering messages depends on the information of nodes' location and moving direction. It is complex and difficult to deal with these location and moving direction information when the nodes number extends to a high number. At the same time, it is possible that one node may not obtain the accurate information so as to causing packet delivery failure.

To summarize, these experiments show that LDPR is not able to guarantee good performance when the number of nodes is large. It states that LDPR is not good at scalability. Figs. 21 and 22 represent the same phenomenon under various transmission rate and different number of sessions. Of course, the packet delivery ratio with respect to 150 nodes is higher than which with regards to 20 nodes. It means that we should choose a suitable nodes density in the real applications in order to achieving the best performance.

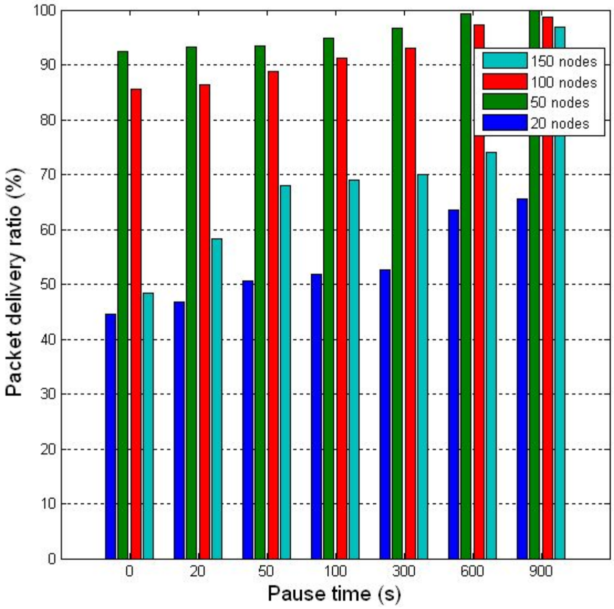


Figure 20. Packet delivery ratio versus pause time under different nodes density

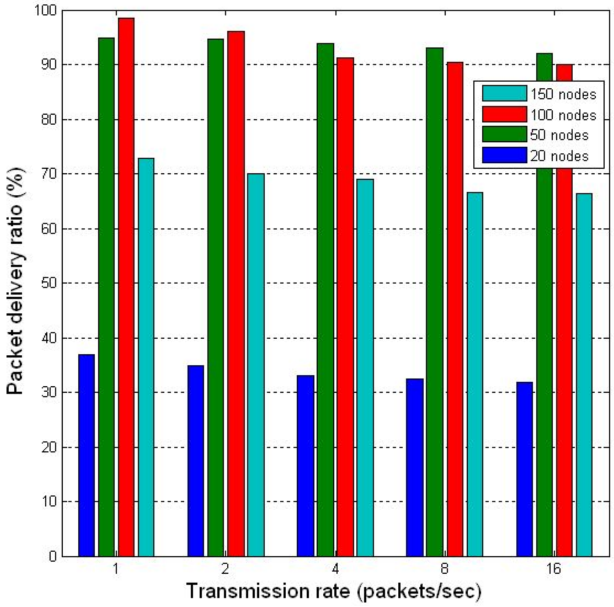


Figure 21. Packet delivery ratio versus transmission rate under different nodes density

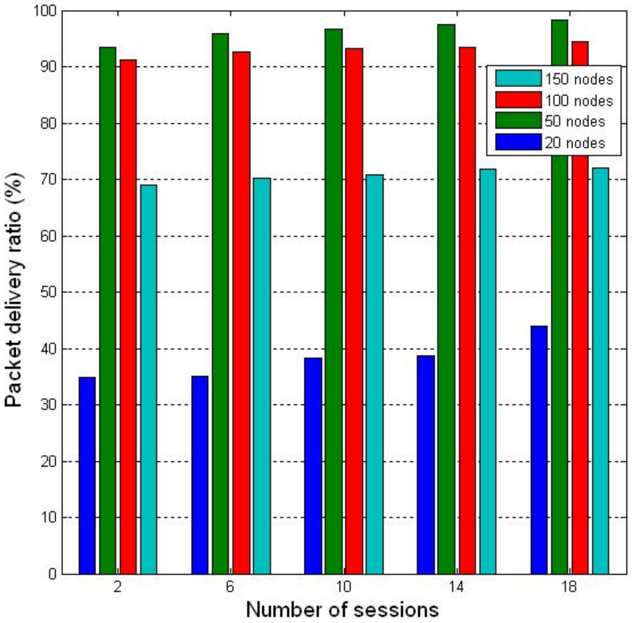


Figure 22. Packet delivery ratio versus number of session under different nodes density

4.2.5 Effect of Buffer Size

Another aspect we observed is that the influence of buffer size on the packet delivery ratio. We think over five situations, which includes the node's buffer size are 10, 50, 100, 500, and 1000. We also choose pause time, transmission rate and number of sessions as the parameters of X axis, and only consider the packet delivery ratio as the parameter of Y axis. Figs. 23, 24, and 25 illustrate the influence of the buffer size on the packet delivery ratio based on pause time, transmission rate, and number of sessions, respectively.

In general, the influence of buffer size is evident on the packet delivery ratio. The change of the packet delivery ratio is notable as increasing the buffer size. In particular, the packet delivery ratio exceeds 90% when the buffer size is larger than 50 in all the metrics. Moreover, the packet delivery ratio can reach to 100% when the buffer size is over 500 in all the metric. Only if the buffer size equals to 10, the packet delivery ratio has a significant decline. Figs. 23, 24, and 25 reveal that buffer size is an important factor in DTNs and always has a heavy impact of the performance of the routing protocols in DTNs. Specially, in LDPR, buffer size can be more efficiently utilized and managed. We can achieve a high packet delivery ratio under a reasonable buffer size.

To summarize, these simulations state that LDPR is able to guarantee good performance in the presence of normal buffer size (around 50). LDPR doesn't need infinite buffer size to ensure the packet delivery ratio such like in Epidemic. According to real environment and real resource consumption, we can decide the suitable buffer space in order to obtain good performance by utilizing LDPR, in comparison to the other protocols taken into consideration.

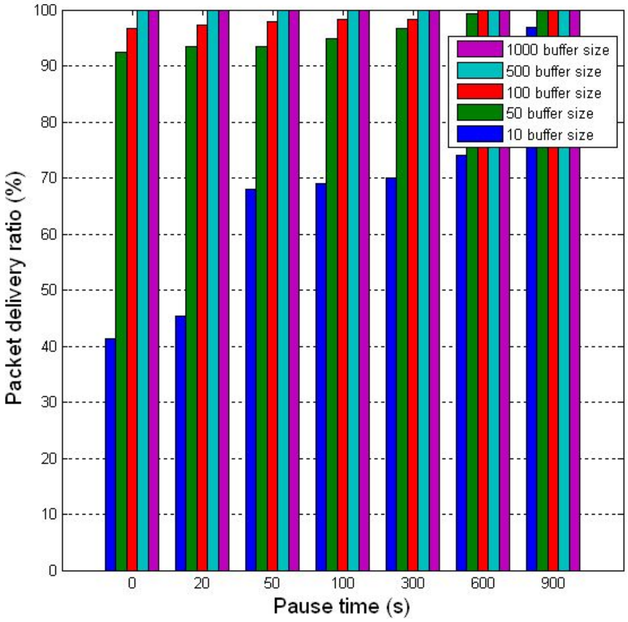


Figure 23. Packet delivery ratio versus pause time under different buffer size

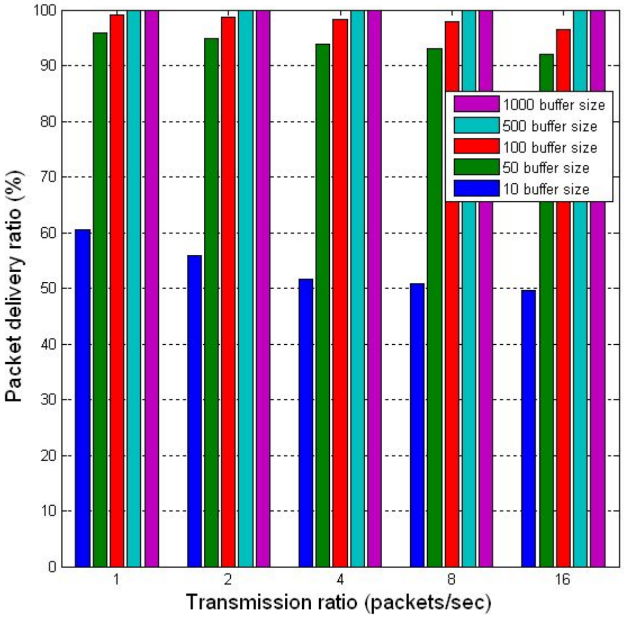


Figure 24. Packet delivery ratio versus transmission rate under different buffer size

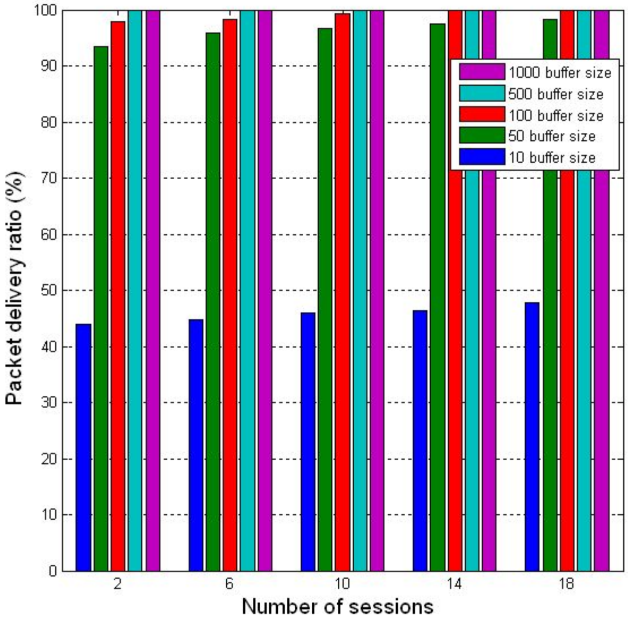


Figure 25. Packet delivery ratio versus number of session under different buffer size

5. Conclusions

In this paper, we have investigated delay tolerant networks, where a lot of new applications are viable, vouching for an exciting future if the underlying mechanisms are presented. Therefore, we have proposed a routing protocol named *Location and Direction Aware Priority Routing* (*LDPR*) for DTNs, which utilizes the location and moving direction of nodes to deliver a message from source to destination. We have shown that a node can get the location and moving direction of other nodes by receiving beacon packets periodically from anchor nodes and referring to received signal strength indicator (RSSI) for the beacon. LDPR contains two schemes named transmission scheme and drop scheme, which take advantages of the nodes' information of the location and moving direction to transmit the message and store the message into buffer space, respectively.

The simulation experiments have shown that LDPR is able to ensure the validity and integrity of the messages, and the buffer size in LDPR can be efficiently utilized and managed so as to achieve a high packet delivery ratio. Moreover, LDPR is able to guarantee good performance with a lower routing overhead in the presence of suitable buffer size. However, LDPR is not good at scalability and can be only implemented in the environment which focuses on the validity and integrity of the message rather than delivery delay. Our future work is to overcome these problems to design a more robust routing protocol for harsh operational environments.

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저작물 이용 허락서

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논문제목	한글 : 지연 허용 네트워크에서 위치와 방향을 고려한 우선순위 라우팅 영문 : Location and Direction Aware Priority Routing for Delay Tolerant Networks				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건 아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함.
   다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

2009년 월 일

저작자: 심 검 (서명 또는 인)

조선대학교 총장 귀하