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移动自组网中基于渗流理论的概率可靠分发协议*

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Percolation-Based Probabilistic Reliable Dissemination for Mobile Ad Hoc Networks

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Abstract: This paper proposes PLPD, a novel percolation-based probabilistic reliable dissemination protocol for information dissemination among a group of nodes in a MANET. Being different from other probabilistic reliable dissemination protocols, PLPD is aware of the network topology and directed dissemination, which doesn't require flooding the network with control messages to manage group members. In PLPD, each group member maintains only a partial view of other members in its neighborhood and disseminates data messages with probability p to a subset of the view. The dissemination process of the PLPD protocol is modeled with the percolation theory, and it is proved that PLPD can achieve a probability close to 1 for all group members to receive every message, if p is greater than a certain critical threshold. The simulation results show that the PLPD protocol effectively reduces the network load while providing high reliability, and scales well to large system sizes.
Key words: MANET; percolation; dissemination; probability; phase transition

摘　要: 提出了基于渗流理论的概率可靠分发协议(PLPD).与其他概率可靠分发协议不同,PLPD 协议感知节点的地理信息并进行有向分发,不需要泛洪控制信息来进行组成员管理.在 PLPD 协议中,每个组成员只需维护其邻近区域中部分其他组成员视图,并以一定的概率向视图中的成员转发消息.采用渗流理论对 PLPD 协议的分发过程建模,从理论上证明了当分发概率参数大于某个阈值时,PLPD 使每个消息被分发到所有组成员的概率为 1.模拟实验表明,PLPD 协议在获得高可靠性的同时有效地减少了网络负载,并在大规模移动自组网络中有较好的可扩展性.
关键词: 移动自组网络;渗流;分发;概率;阶段跃变
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1 Introduction

In a mobile ad hoc network (MANET), reliable group communication protocols are essential for many important system functions and applications, such as mobility management, distributed management of cryptographic keys or certificates. Due to the highly dynamic and unpredictable changes to the network topology, traditional solutions for wired networks are not directly applicable to MANETs and new protocols are needed.

Recently, probabilistic reliable dissemination has gained popularity as a robust and scalable approach to propagating information in MANETs. The principle underlying the probabilistic reliable dissemination protocols mimics the spread of epidemics or rumor, and the idea common to these protocols is to have each node in a group forward the messages that it has received to a random set of other nodes in the group. Many application can be found, including consistency management in replicated databases[1] and *gossip* (or *epidemics*) *information dissemination* for reliable multicast[2−4], However, most of these previous research is for wired networks. For MANETs, a seminal probabilistic reliable dissemination protocol called Anonymous Gossip (AG) protocol is proposed in Ref.[5]. AG uses MAODV as the underlying protocol to multicast the message, and then uses gossip to recover the lost messages by obtaining them from other members of the group that might have received it. Other efforts that make use of gossiping techniques for multicasting in MANETs[5−7] similarly lack an analytical prediction of their reliability. The Route Driven Gossip (RDG) multicast protocol proposed in Ref.[8] gossips uniformly about multicast packets, negative acknowledgements, and membership information. But a node seeking to join a group floods the network with a Group-Request message, and the gossip destination is likely to be a remote node.

Several fundamental issues need to be addressed in developing epidemic dissemination protocols for MANETs. First, the reliability of epidemic algorithms relies on the fact that every node forwards every message it receives to a subset of nodes chosen *uniformly* at random among *all* the nodes in the system. To ensure this property is not trivial in MANETs. Second, the probabilistic reliable dissemination protocols discussed so far are oblivious to the underlying network topology and assume that all nodes are equally reachable, without taking into account the fact that the hops between two nodes has effect on the stability of the path and the cost of the bandwidth in MANETs. Therefore, it is perfectly possible that a message is forwarded from a node to a very close node via a remote one.

In this paper, we present PLPD, a novel PercoLation-based Probabilistic reliable Dissemination protocol, which achieves high reliability while alleviating the above problems. It has the following features: (1) Each node maintains only a partial view of other members in its neighborhood, and those nodes do not need to be a uniform sample of other member nodes; (2) Each node in a group forwards the message that it has received with probability p to a subset of other member nodes in the neighborhood in some directions. Thus the networks load is decreased; (3) PLPD does not require a multicast or unicast primitive at the network layer in order to improve the adaptability to the technology development in the future.

The PLPD protocol is modeled after the percolation theory. It is proved that PLPD can achieve a probability 1 for all group nodes to receive every message if the forwarding probability is greater than a certain critical threshold. Extensive experiments have been performed using the NS-2 network simulator. Simulation results verify the theoretic analysis results and show that PLPD efficiently reduces the network load while providing high reliability, and scales well to large system sizes.

2 System Model

Before presenting the PLPD protocol, we first describe the network model and assumptions. The network consists of a set ℕ of nodes with the same computation and transmission capabilities. The nodes communicate with each other through bidirectional wireless links. $Group\subset\mathbb{N}$ is a set of member nodes in a group, and every group has a unique ID, *GroupID*. We assume that every node has a unique physical address or ID (*nodeID*), and knows its own location information (*Location*), which can be achieved by using GPS or via other location services.

The PLPD protocol is designed to disseminate messages among the nodes in a $Group\subset\mathbb{N}$, and to provide probabilistic reliability instead of perfect guarantees such as "all messages sent by a source will eventually be received by all group members". Two metrics are used for measuring the performance of the PLPD protocol. The first is *degree of reliability* R_d, which is the average ratio between the number of members receiving a message sent by a certain source and the size of the group. The second is *network load* N_l, which is the average number of $message\times hop$ per unit time required to achieve a certain R_d. N_l takes into account only the load generated by our protocols. Our goal in designing PLPD is to design a dissemination protocol that can achieve high reliability degree R_d even in large scale networks. At the same time, the network load N_l should be kept at a reasonable level even if the node mobility, the scale of the network, and the size of the group increase.

3 PLPD Protocol

3.1 Data structures and message types

Each group member maintains the following data structures:

- Node Identifier (*nodeID*): The node ID uniquely identifies a node. Each node also has two attributes: its group identifier (*GroupID*) and its geographic location information (*Location*).
- Data Buffer (*Data Buffer*): The buffer stores the messages received. If the buffer is full, the oldest message is removed.
- Member view (*View*): The view contains the *nodeID*s of the subset of known members in the neighborhood of this node. It is divided into two parts: *View.Out* contains the *nodeID*s of the members that are selected to disseminate data messages from this node; *View.In* contains the members that disseminate data messages to this node. The view of node $i\in Group$ is denoted as $View_i^{Group}$.
- Forwarding table (*Forwardlist*): The table is used for recording the next hop to the dissemination destination node. It contains [*nodeID*,*NextnodeID*,*Actflag*,*Timer*1,*Timer*2], where *nodeID* is the ID of the destination node, *NextnodeID* is the ID of the next hop node to the destination node, *Timer*1 and *Timer*2 are timeout counters, and *Actflag* is the flag to represent the state of the routing (*Actflag*=true represents that this routing is active).

There are two types of messages, *data messages* and *control messages*. Each *message* is uniquely identified by its identifier *mid*, which is a tuple [*GroupID*,source *nodeID*,message sequence *mNo.*]. A member can detect the missing messages by observing the message ID sequence.

3.2 Membership management

In the MANET environment, the cost for one group member to maintain all others' information is very high. To reduce the cost, the PLPD protocol takes the network topology into account to let each group member maintain only a partial view of the group membership. Each member needs to know only some members in its neighborhood. Membership management of the PLPD protocol builds connections among the group members by using the following three primitives:

- GroupSearch (*srcNodeID*,*gid*,*range*): The *Search* message is flushed by a member to find other group members in its neighborhood. Here *srcNodeID* is the *nodeID* of the initiator node; *gid* is the *groupID* to search for; and *range* is the searching area. The *Search* message contains the *nodeID* and *location* information of the node that initializes the search request.

- GroupReply (*srcNodeID*,*gid*,*dstNodeID*): When a group member receives a *Search* message, it replies with the *Reply* message, which contains its nodeID and location information. Here *srcNodeID* is the *nodeID* of the node that initializes the *GroupSearch* primitive; *gid* is the *groupID* to search for; and *dstNodeID* is the *nodeID* of the node returning the *Reply* message.
- Activate (*srcNodeID*,*dstNodeID*): This primitive produces *ActivateInfor* message to activate the routing between two members (the *Actflagv* is set to true) and then builds connections between them. Here *srcNodeID* refers to the source node of the routing activated and *dstNodeID* is the *nodeID* of destination node of the routing activated.

3.3 Protocol presentation

According to the functionality, the operations of the PLPD protocol can be classified into three sessions: *Join session*, *Dissemination session*, and *Leave session*. Each member executes the *Join session* periodically to build connections with other group members. The *Join session* is also used by a node newly joining a group. The *Dissemination session* is executed when a group member produces a data message or forwards a data message received. The *leave session* defines the behavior of a node leaving the group.

- Join session: When a node wants to join a group, it uses the expanding ring search approach and calls the *GroupSearch* primitive to search for other members in its neighborhood. Each group member builds a right-angle coordinate system with itself as the origin. The coordinate system is divided equally into eight sectors and each sector is with angle 45°. The search stops when at least one group member is found in each sector.

Upon receiving the *Search* message, the group member sends the *Reply* message to the initiator node and calculates the initiator’s location. If the initiator node is the nearest node in a sector, the *View.Out* is refreshed with the *nodeID* of the initiator and the routing from this node to the initiator is activated. According to the *Reply* message received, the initiator node of the *GroupSearch* primitive refreshes its *View.Out* with the nearest node’s *nodeID* in each sector, and calls the *Activate* primitive to activate the routing information of all intermediate nodes along the paths from it to every group members in its *View.Out*. Each group member executes *Join session* periodically to refresh connections among members and gets the newest members view in eight directions and the routing information to them.

- Dissemination session: When a group member produces a data message or receives a new data message from another member, it disseminates the message with probability *p* to all the nodes in *View.Out*, except the node from where it receives the message. When the group member receives a data message, it refreshes its *Data buffer*.
- Leave session: When a group member intends to leave the group, it sets the leave flag to *true* and disseminates the *leave* message to each member in *View.In*. When a group member receives a *leave* message, it executes *Join session* to re-build group membership if the leaving node is in its *View.Out*.

In the PLPD protocol, each member node chooses no more than 8 other members in its neighborhood to probabilistically disseminate data messages. The number of nodes to be chosen is independent of the size of networks and the group. At the same time, the range of searching for members is limited in the neighborhood of the node itself, so that the networks load for member management is kept at a reasonable level. Therefore, PLPD scales well to the large system size.

4 Analysis

4.1 The percolation theory

The percolation theory studies the flow of fluid in random media and has been generally credited as being introduced in 1957 by Broadbent and Hammersley, which is based on a probabilistic model and exhibits an interesting phenomenon known as the *phase transition*. A *phase transition* occurs when a system undergoes a sudden change of state: small changes of a given parameter in the system induce a great shift in the system's global behavior. This abrupt transition occurs at a specific value p_c called the critical point or the critical threshold. The *phase transition* observed in percolation theory has been applied to reduce the traffic for multicast in wired networks[2] and to study the optimum power ranges for connectivity in wireless networks[9,10]. In Ref.[11,12], it is used to enhance connectivity or reduce flooding in MANETs. Two main models of the percolation theory are introduced as follows:

Bond percolation model

In the standard bond percolation on a graph $G=(V,E)$ with parameter $p\in[0,1]$, each edge $e\in E$ is independently assigned value 1 (*open*) with probability p, or value 0 (*closed*) with probability 1-p. Here μ_{BP}^{p} represents the corresponding product probability measure on $\{0,1\}^E$. A *cluster* is a (maximal) connected component of the open edges. The primary focus of the percolation theory is on the possible occurrence of infinite clusters. Then we have the existence of a critical value $p_c^{bond}=p_c^{bond}(G)\in[0,1]$ such that

$$\mu_{BP}^{p}(\exists \text{ some infinite cluster})=\begin{cases}0, & \text{if } p<p_c^{bond}\\ 1, & \text{if } p>p_c^{bond}\end{cases}.$$

Site percolation model

Site percolation on $G=(V,E)$ with parameter $p\in[0,1]$ is similar to the bond percolation, except that the randomness is on the vertices rather than on the edges: each vertex $v\in V$ is independently assigned value 1 (*open*) with probability p, or 0 (*closed*) with probability 1-p. Here μ_{BP}^{p} represents the resulting probability measure on $\{0,1\}^V$. Clusters are defined similarly, and we have the existence of a critical value $p_c^{site}=p_c^{site}(G)\in[0,1]$ such that

$$\mu_{BP}^{p}(\exists \text{ some infinite cluster})=\begin{cases}0, & \text{if } p<p_c^{site}\\ 1, & \text{if } p>p_c^{site}\end{cases}.$$

According to the percolation theory, $p_c^{bond}\le p_c^{site}$, for any graph $G=(V,E)$.

4.2 Analysis of PLPD performance

We model the PLPD protocol with the percolation theory and prove the correctness of the PLPD. The topology of connections between all pairs of members produced by **Join session** in the PLPD is denoted by the directed graph $G=(V,E)$, where V is the set of all member nodes in *Group*; edge $(i,j)\in E$, if and only if $i,j\in Group$ and $j\in View.out_i^{Group}$. So every message issued by every member node is disseminated to other members along the edges of G. In the directed graph G produced by the PLPD, the open of edge (i,j) in the bond percolation model is interpreted as saying that j is one of the i's data dissemination targets, and likewise the close of edge (i,j) is interpreted as saying that data messages is not disseminated from i to j. The probability of the edge being open corresponds to the dissemination probability p in the PLPD. The *cluster* defined in the bond percolation model corresponds to a (maximal) connected component of edges in G along which data messages are disseminated. Therefore, the success of the PLPD protocol corresponds to the existence of at least one infinite *cluster* in G. That is to say, if we have the existence of a critical value $p_c^{bond}(G)<1$, then if only dissemination probability $p>p_c^{bond}(G)$, the probability that all a group members receive a certain message tends to be 1. Otherwise, if $p< p_c^{bond}(G)$, that probability is 0.

For simplicity, it is supposed that member nodes are with λ Poisson distribution. It is proved at first that G is a connected graph.

Lemma 1. Let $s\in\Re^2$ be a point and C be a sector originating at s with an angle of $\frac{\pi}{4}$. Furthermore, let q and r be two points in C with $|s,q|\le|s,r|$, then $|q,r|\le|s,r|-\left(1-2\sin\left(\frac{\pi}{8}\right)\right)|s,q|$.

Proof: Consider Fig.1. In this figure, q' represents the point on the line from s to r, and $|s,q'|=|s,q|$. Applying the triangle inequality to q, q' and r, we get

$$|q,r|\le|q,q'|+|q',r| \tag{1}$$

$|q,q'|$ is certainly maximized if q, q' are on the opposite sides of the sector. Hence,

$$|q,q'|\le 2\sin\left(\frac{\pi}{8}\right)|s,q| \tag{2}$$

Moreover,

$$|q',r|=|s,r|-|s,q'|=|s,r|-|s,q| \tag{3}$$

Plugging Eq.(2) and Eq.(3) into Eq.(1) yields

$$|q,r|\le 2\sin\left(\frac{\pi}{8}\right)|s,q|+|s,r|-|s,q|=|s,r|-\left(1-2\sin\left(\frac{\pi}{8}\right)\right)|s,q| \qquad \square$$

Theorem 2. $G=(V,E)$ is connected, and the length of the shortest path between any pair of nodes in G is $\frac{1}{1-2\sin\left(\frac{\pi}{8}\right)}\approx 4.262$ times shorter than the Euclidean distance between them.

Proof: Given a source-destination pair(s,t), consider the following strategy to get from s to t: Always take the shortest edge whose other endpoint lies in the same sector as t. Let the path obtained by this rule be $(s=v_0,v_1,v_2,\ldots,v_k=t)$. The path indeed starts at s and ends at t. Therefore, $G=(V,E)$ is connected.

Because the sector is with an angle of $\frac{\pi}{4}$, we are guaranteed to have

$$|v_i,t|>|v_{i+1},t|,$$

for all $i=0,\ldots,k-1$ (see Fig.2).

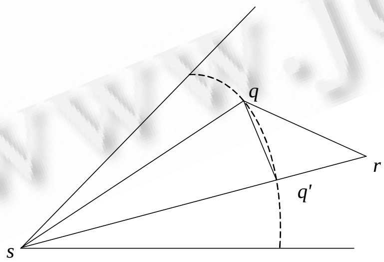


Fig.1 The sector of *s*

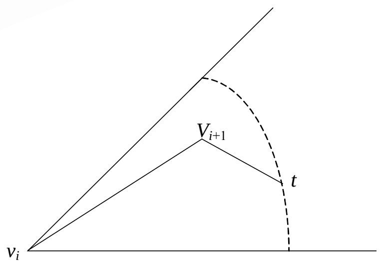


Fig.2 Figure illustrating of Theorem 2

Using Lemma 1, it holds that

$$\sum_{i=0}^{k-1}|v_{i+1},t|\le\sum_{i=0}^{k-1}\left(|v_i,t|-\left(1-2\sin\left(\frac{\pi}{8}\right)\right)|v_i,v_{i+1}|\right).$$

Rearranging the terms yields

$$\sum_{i=0}^{k-1}|v_i,v_{i+1}| \le \frac{1}{1-2\sin\left(\frac{\pi}{8}\right)}\sum_{i=0}^{k-1}(|v_i,t|-|v_{i+1},t|)=\frac{1}{1-2\sin\left(\frac{\pi}{8}\right)}|s,t|. \qquad \square$$

Theorem 3. In the PLPD protocol, every message is disseminated to all group members with probability 1.

Proof: We prove that the probability that all members in a group receive a certain message is 1 by showing the existence of $p_c^{bond}(G)<1$.

Because of $p_c^{bond}(G)\le p_c^{site}(G)$, $p_c^{bond}(G)<1$ as long as we can prove $p_c^{site}(G)<1$.

$p_c^{site}(G)$ is independent of the choice of node distribution density λ, so we are free to choose $\lambda>0$ as we wish.

Z^2 lattice is built on two-dimensions space of G, and is denoted as G'.

Set $\varepsilon>(1-p_c^{site}(G'))/3$, where note that since $p_c^{site}(G')<1$, we have $\varepsilon>0$.

Pick the Poisson intensity λ large enough so that the probability of seeing no nodes of G in the square $\left[0,\frac{1}{11}\right]^2$ satisfies

$$P\left(V\cap\left[0,\frac{1}{11}\right]^2=\varnothing\right)\le\frac{\varepsilon}{242}.$$

And then pick M large enough so that the probability that the number of nodes of G in the square $\left[0,\frac{1}{11}\right]^2$ is larger than M satisfies

$$P\left(V\cap\left[0,\frac{1}{11}\right]^2>M\right)\le\frac{\varepsilon}{242}.$$

Let $A_{0,0}$ be the event that for i,j=0...10 we have at least one and at most M nodes of G in the square $\left[\frac{i}{11},\frac{i+1}{11}\right]\times\left[\frac{j}{11},\frac{j+1}{11}\right]$. Note that $A_{0,0}$ depends only on the nodes in the unit square $[0,1]^2$. For k, $l\in Z$, let $A_{k,l}$ be the obviously analogous event concerning the square $[k,k+1]\times[l,l+1]$. The events $\{A_{k,l}\}_{k,l\in Z}$ are clearly i.i.d., and therefore we have

$$P(A_{k,l})\ge 1-121\frac{\varepsilon}{242}-121\frac{\varepsilon}{242}=1-\varepsilon.$$

Set $p=1-\frac{\varepsilon}{121M}$, and do site percolation on G with parameter p.

Let $B_{k,l}$ be the event that all nodes in $[k,k+1]\times[l,l+1]$ are open, and also define $C_{k,l}=A_{k,l}\cap B_{k,l}$. We see that the events $\{C_{k,l}\}_{k,l\in Z}$ are i.i.d., with each $C_{k,l}$ having probability

$$\begin{aligned}P(C_{k,l})&=P(A_{k,l})P(B_{k,l}\mid A_{k,l})\\&\ge(1-\varepsilon)p^{121M}\\&\ge(1-\varepsilon)\left(1-121M\times\frac{\varepsilon}{121M}\right)\\&\ge(1-\varepsilon)^2>1-2\varepsilon>P_c^{site}(G').\end{aligned}$$

Hence the set of $(k,l)\in Z^2$ for which $C_{k,l}$ happens, contains an infinite cluster with probability 1 by the choice of ε, while being viewed as a site percolation process on G'.

We construct a cluster H in G as follows. For all $k,l\in Z$, whenever (k,l) and $(k+1,l)$ belong to an infinite cluster of G', if any two nodes in $\left[k+\frac{5}{11},k+1+\frac{6}{11}\right]\times\left[l+\frac{5}{11},l+\frac{6}{11}\right]$ satisfy $|x_1-x_2|\le\frac{2}{11}$ and $|y_1-y_2|\le\frac{1}{11}$, from Theorem 2, these two nodes are connected and the length of the shortest path between them is less than $\frac{\sqrt{5}}{11}\times 4.262\approx 0.8664$. Therefore, the shortest path between these nodes is in the square $[k,k+2]\times[l,l+1]$. Hence between any pair of two nodes in $\left[k+\frac{5}{11},k+1+\frac{6}{11}\right]\times\left[l+\frac{5}{11},l+\frac{6}{11}\right]$, there is at least a path in the square $[k,k+2]\times[l,l+1]$. All nodes in $\left[k+\frac{5}{11},k+1+\frac{6}{11}\right]\times\left[l+\frac{5}{11},l+\frac{6}{11}\right]$ are included in cluster H. All nodes on the shortest paths between any two nodes, which are in $\left[k+\frac{5}{11},k+1+\frac{6}{11}\right]\times\left[l+\frac{5}{11},l+\frac{6}{11}\right]$ and satisfy $|x_1-x_2|\le\frac{2}{11}$, and $|y_1-y_2|\le\frac{1}{11}$, are included in cluster H too. Obviously, cluster H is connected. Similarly, whenever (k,l) and $(k,l+1)$ belong to an infinite cluster of G', all nodes in $\left[k+\frac{5}{11},k+\frac{6}{11}\right]\times\left[l+\frac{5}{11},l+1+\frac{6}{11}\right]$ and all nodes on the shortest path between any two nodes, which are in $\left[k+\frac{5}{11},k+\frac{6}{11}\right]\times\left[l+\frac{5}{11},l+1+\frac{6}{11}\right]$ and satisfy $|x_1-x_2|\le\frac{1}{11}$ and $|y_1-y_2|\le\frac{2}{11}$, are included in cluster H. Obviously, H constructed as above is an infinite connected cluster of G. It reveals that the existence of an infinite cluster in G' implies the existence of an infinite cluster with probability 1 in G when a site percolation is done on G with parameter p. Hence $p_c^{site}(G)<p$, then $p_c^{bond}(G)\le p_c^{site}(G)<p<1$. □

5 Simulation

This section presents the practical evaluation of our PLPD protocol. Firstly, we validate the correctness of Theorem 3. Secondly, we evaluate the metric defined in Section 2 (R_d and N_l) of PLPD protocol by comparing with the Route Driven Gossip (RDG)[8] protocol in the case of different group sizes and movement speeds.

5.1 Simulation environment

The NS-2 is used in simulations. We simulate a mobile ad hoc network with 200 nodes in a 1400m×1400m area, operating over 400 seconds. Transmission rate of nodes is 2Mbps and a nominal transmission range is 250m. The movement pattern is defined by Random Waypoint model. Each node has a maximum speed between 2~20m/s and an average pause time of 40s.

In simulations, the network contains a single group. At the beginning, the members consecutively send *join* messages at intervals of 3 seconds to apply to join the group until at least one member is found in each 45º sector or the search range is bigger than the bound (*range*Max). Then one of the members is selected randomly to generate one data message and each member transmits messages at intervals of 3s. In the process of expanding the ring search, $rang_0$ is set to 2 hops and *range*Max is set to 4 hops. The **Join session** period is set to 30s. Each simulation is carried out 10 times with different scenario files created by NS-2.

5.2 The phase transition

In order to validate the occurrence of the phase transition we perform a series of simulations. There are three scenarios in the simulations, where the number of mobile nodes is 200; the size of group is 50,100 and 200 respectively. One of the group members is selected randomly to generate a data message. The maximum node speed is 2m/s.When some nodes execute the expanding ring algorithm, the search range may reach *rangeMax* while there is no member in some sectors. Therefore in the implementation of the PLPD protocol if the number of sector (in which some members locate) n is less than m=8*p, the fanout (the number of dissemination destinations for each **Dissemination session**) is set to n; otherwise, the fanout is set to m=8*p. The values in Fig.3 are the average value of 10 simulation results. It is shown in Fig.3 that the phase transition occurs at p=0.4, which validates Theorem 3 very well. Therefore the critical probability is less than 0.4. It is to say that if the fanout is greater than 3, the probability of all group members receiving every message tends to be 1.

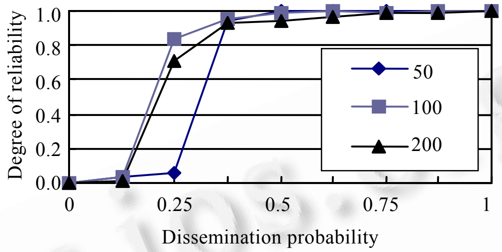


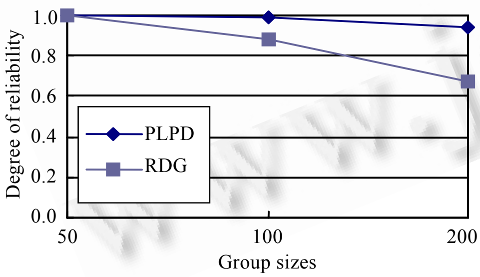
Fig.3 Reliability of PLPD protocol with dissemination probability varying from 0.1 to 1

5.3 Comparing PLPD and RDG

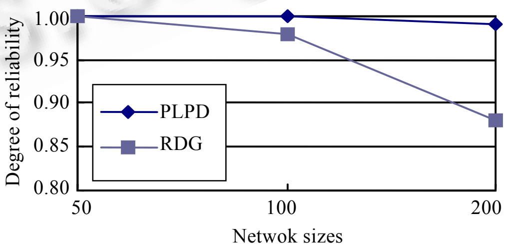
The comparison is done between PLPD and RDG in our simulations. According to the simulation results, the “good” parameter values F=4 and τ_q=1 are selected to implement the RDG protocol. Here F (the *fanout*) is the number of gossip destinations for each gossip emission. The dissemination probability p=0.5, i.e., the *fanout*=4 is selected in the PLPD protocol.

1) The *Degree of Reliability* of protocols with different group/network sizes

As shown in Fig.4, PLPD is more reliable than RDG in different network environments. We also note that only a slight reliability degradation is observed in PLPD when the group size or network size is increased. In fact, the locality of traffic in PLPD greatly improves the reliability. Contrarily, the gossip destinations which are selected randomly are perhaps remote nodes in RDG, and the longer the path of dissemination is, the higher the message loss probability is. Therefore the *Degree of Reliability* (R_d) of RDG is lower than that of PLPD.



(a) Reliability of protocols. The maximum node speed is 2m/s. The network size is 200



(b) Reliability of the PLPD protocols. The group size is half of the network size and the maximum node speed is 2m/s

Fig.4

2) The *Degree of Reliability* of protocol with different movement speeds

Simulation results exhibit that when the mobility is increased, the decrease of R_d of PLPD is slower than that of RDG (Fig.5). The reason is that higher speed results in more route invalidation, which in turn causes member rediscovering process. Because the member rediscovering process and data dissemination are local in PLPD and globe in RDG, when the node speed increases, the R_d of PLPD degrades much slightly than that of RDG.

3) The *Network Load* of protocol with different group sizes

The *Network Load* (N_l) defined in Section 2 basically counts the total network-level hops traveled by all messages corresponding to the delivery of one message to the whole group in the simulation. Fig.6 shows the N_l of both PLPD and RDG with different group sizes. From Fig.6, we can have two main observations: (1) The N_l increases linearly with group size growing in the PLPD protocol; (2) The N_l of the PLPD is greatly lower than that of RDG. In fact, both the member management and the selection of data dissemination destinations in PLPD are local and are not related to the remote nodes. But in RDG every join message is broadcasted in the whole network to search other members and gossip destinations perhaps are remote nodes, so that when group sizes and network sizes increase, the increase of N_l in PLPD is observably slower than that in RDG.

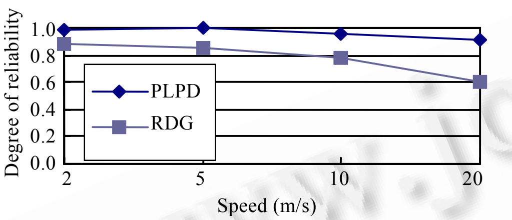


Fig.5 Reliability of PLPD and RDG protocols in a network of 200 nodes with half of them in a group

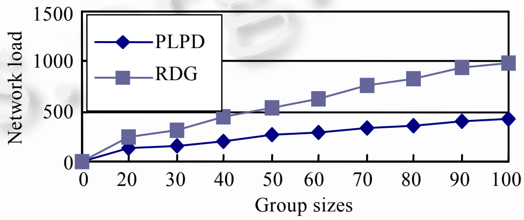


Fig.6 The *Network Load* of the PLPD and RDG protocols in a network of 200 nodes. Maximum node speed is 2m/s

6 Conclusion

A novel percolation-based probabilistic reliable dissemination protocol (PLPD) for MANET is presented in this paper. In PLPD, each member disseminates data messages with probability p to its neighboring members in different directions. Because the member management and data dissemination is local and directional, PLPD efficiently decreases the network load while maintains high reliability. In this paper, percolation theory is used to model and analyze the PLPD protocol, and it is proved that PLPD makes the probability of all group members receiving every message tends to be 1 if p is greater than a certain critical threshold. Extensive simulations validate the results of theoretical analysis and show that comparing to similar probabilistic dissemination protocol, PLPD efficiently decreases the network load in large network sizes. In terms of future work, we intend to optimize our PLPD protocol according to the requirement of upper layer applications and improve the practicality of PLPD.

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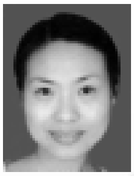

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