Ticket-based Multiple Packet Broadcasting in Delay Tolerant Networks

Yunsheng Wang and Jie Wu

Department of Computer and Information Sciences
Temple University
Philadelphia, PA 19122
Email: {yunsheng.wang, jiewu}@temple.edu

Abstract

In delay tolerant networks (DTNs), broadcasting is an important routing function that supports the distribution of data to all users in the network. Efficient broadcasting in DTNs is a challenging problem due to the lack of continuous network connectivity. In this paper, we consider the limited bandwidth scenario for DTN broadcasting. Our scheme aims to provide a ticket-based multiple packet broadcasting protocol for a DTN that follows the human mobility patterns – Levy walks and community-based mobility. Our proposed protocol has two steps: *packet selection* and *relay node selection*. Packet selection takes place when two nodes come into contact with each other. It is based on a packet priority ranking scheme, which considers the number of tickets associated with each packet. Relay node selection will consider two parameters: *global active level* and *local active level*. Global active level is used for determining when the ticket partition is needed, and local active level is used to decide how the tickets should be partitioned. Each local active level corresponds to the activity level in a grid of 2-D broadcast space. Compared with epidemic, time-based, and hop-count-based schemes, our ticket-based packet priority ranking scheme, which considers the mobility patterns and the node active levels, has the best performance in our simulation. The simulation results show the good performance of our proposed scheme in DTN broadcasting, both in synthetic and real mobility traces.

Key words: Broadcasting, delay tolerant networks (DTNs), routing, ticket-based.

Ticket-based Multiple Packet Broadcasting in Delay Tolerant Networks

Yunsheng Wang and Jie Wu

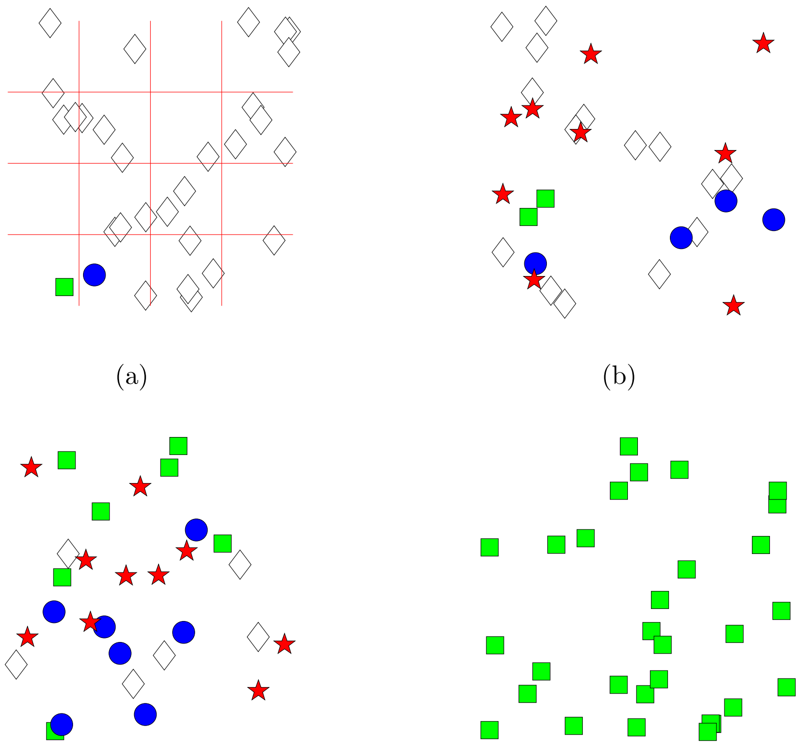
Department of Computer and Information Sciences
Temple University
Philadelphia, PA 19122
Email: {yunsheng.wang, jiewu}@temple.edu

1. Introduction

Recent years have shown rapid growth in the popularity and capabilities of handheld devices, such as mobile phones and laptops. Delay tolerant networks (DTNs) [6] technologies have been proposed to allow mobile nodes in such extreme networking environments to communicate with one another. In DTNs, most of the time, there does not exist an end-to-end path between some or all of the nodes in the network.

Several DTN routing protocols have been proposed [17, 22, 23, 24]. However, having an efficient broadcasting scheme is equally important. The broadcasting approaches proposed for Internet or mobile ad hoc networks cannot be directly applied to DTNs because of intermittent connectivity among the nodes in DTNs. Existing broadcast routing protocols in DTNs [9, 11] do not consider situations with limited bandwidth and a choice of multiple packets to transmit. In this paper, we propose a novel DTN broadcasting scheme which considers multiple packet ranking where there are limited bundles of packets that can be forwarded in each contact.

In recent years, biologists have found that *Levy walks* can be used to describe the mobility patterns of foraging animals [20]. Computer scientists also paid attention to this area of research. They studied Levy walks in human mobility [8, 15], which can help us to analyze wireless mobile networks, such as DTNs. Human movements have patterns to them. For example, we go to work, meetings, favorite places, etc. These are not random movements. Recently, there has been some research done with the community-based mobility model [14, 18]. The mobile nodes tend to move and stay at local sets



(a) (b)

(c) (d)

Figure 1: An example for multiple packet broadcasting: circle nodes with packet 1, star nodes with packet 2, square nodes with both packets, and diamond nodes with no packets.

of frequently visited places for most of the time, while occasionally roaming to other places. Thus, nodes often meet other nodes that also move and stay within the same set of frequently visited places while, by chance, meeting nodes of other areas. Hence, considering Levy walks and the community-based mobility model, we divide the network into grids, and nodes in the same grid have more of a chance to meet with each other.

Broadcasting in DTNs poses some unique challenges when the bandwidth is limited for each contact (for example, one transmission per contact) while there are multiple broadcast packets in the local queue. One key issue is to determine packet ranking and its dynamic ranking adjustment during the broadcast. For example, a relatively "new" packet usually has a higher rank than an "old" packet that has been in the system for a while. Another issue is how to control packet replication during the broadcast process. Various uncertainties in DTNs, including movement and contact distribution, make the distributed ranking adjustment and replication process harder.

In DTNs, it is observed that contacts tend to be clustered in relatively short-term time scales. This clustering effort occurs either in physical space where the physical mobility pattern follows Levy walks or community-based mobility, or in logical space where people congregate in an online social network, such as Facebook and Twitter. We focus only on physical space (although it can be extensible to logical space as well) by partitioning a given 2-D space into square regions (also called grids). We first propose a *quad-grid division* scheme, which divides the network into multiple grids based on recursively dividing a grid into 4 small grids. In the proposed approach, each node maintains its activity levels of all of the grids. Initially, the source node has a given set of tickets for all grids, usually k copies for each grid. In our simulation, the value of k is the number of nodes in the network divided by the grid number. Our protocol contains two steps: the first step is *packet selection*. When two nodes make contact, the forwarding node will select the highest priority packet based on the packet *priority value*, which is jointly decided by three parameters: number of tickets currently held (or simply "ticket"), time in the system (or "time"), and already committed hop count (or "hop-count"). The second step is *relay node selection*. When a ticket carrier a is in contact with another node b, if b has a higher (global) activity level among grids, where b currently holds tickets, than a, then a will redistribute its tickets of certain grids where b has higher (local) activity levels.

Ticket-based packet priority ranking not only considers the packets' characteristics, but also links the global and local active level of the nodes, which is more efficient in DTN broadcasting. The time-based scheme is based on the period the packet travels in the network, which has the global information. Hence, the time-based scheme is considered more useful than the hop-count-based scheme, which only has the local information. We verify the effectiveness of our approach through synthetic and real human mobility trace simulations.

The major contributions of our work are: we use *tickets*, *time*, and *hop-count* to guide the priority ranking of the packets. The notions of *global active level* and *local active level* are introduced to guide the relay node selection. We present a method for area division based on the DTNs mobility patterns: *Levy walks* and *community-based mobility*. The proposed scheme is evaluated in the synthetic and real mobility traces. The simulation results show the better performance of our protocol compared with epidemic routing in DTN broadcasting.

The rest of this paper is organized as follows: Section 2 reviews the related work. Section 3 explains our multiple packets broadcasting scheme. Section 4 focuses on the simulation and evaluation. Section 5 summarizes the work.

2. Related Work

Many broadcast protocols have been proposed to address the challenge of the frequent topology changes in mobile ad hoc networks (MANETs) [13, 21]. Ni et. al discussed many methods for broadcasting in MANETs in [13]. The first one is the probabilistic scheme, which is similar to flooding, except that nodes only rebroadcast with a predetermined probability. The second one is the counter-based scheme, which is an inverse relationship between the number of times a packet is received at a node and the probability of that node being able to reach additional area on a rebroadcast. The third one is the location-based scheme, which uses a more precise estimation of expected additional coverage area in the decision to rebroadcast. In [21], Wu and Dai proposed a broadcast protocol in MANETs based on self-pruning, which is a neighbor knowledge method. Their approach is based on selecting a small subset of nodes to form a forward node set to carry out a broadcast process.

There has also been some recent works which consider broadcasting in DTNs [9, 11]. Goundan, Coe, and Raghavendra discussed a mechanism for energy efficient broadcasting in [9]. This is a k-neighbor broadcast scheme, where nodes do not broadcast all of the time, but wait for an opportunity to reach multiple nodes with one transmission, thereby reducing the number of transmissions overall. In [11], Karlsson, Lenders, and May proposed a design for an open, receiver-driven broadcasting system that relies on delay-tolerant forwarding of data chunks through the mobility of wireless nodes. The system provides public broadcast channels, which can be openly used for both transmission and reception.

Recently, measurement studies of detailed human mobility patterns have been conducted. Based on a six month trace of the locations of 100,000 anonymized mobile phone users, Gonzalez et al. [8] identify that human mobilities show a very high degree of temporal and spatial regularity, and that each individual returns to a few highly frequented locations with a significant probability. In [4], Brockmann, Hufnagel, and Geisel analyze human traveling patterns from the circulation patterns of bank notes, in the scale of several hundred to thousand kilometers, and prove that human long-distance traveling patterns at a macro scale show Levy walk patterns. Rhee et. al studied about one thousand hours of GPS traces involving 44 volunteers in various outdoor settings including two different college campuses, a metropolitan area, a theme park, and a state fair, in [15]. Their work showed that many statistical features of human walks follow truncated power-law, showing evidence of scale-freedom, and do not conform to the central limit theorem. These traits are similar to those of Levy walks. Hu and Dittmann studied heterogeneous community-based mobility model for human opportunistic network [10]. They presented a new synthetic mobility model which had four properties: node heterogeneousness, space heterogeneousness and (short term) time heterogeneousness, (long term) time periodicity. In [12], Musolesi and Mascolo proposed a new mobility model founded on social network theory, which allowed collections of hosts to be grouped together in a way that is based on social relationships among the individuals. This grouping was then mapped to a topographical space, with movements influenced by the strength of social ties that may also change in time. In [19], Thakur et al. addressed issues related to mobile user similarity, its definition, analysis and modeling. They used the users' on-line association matrix to calculate the behavioral distance to capture users' similarity.

The original idea behind geocast was to relate IP addresses to geographic locations in the UUMAP project [3], which maintained a database in which the geographic locations of Internet hosts were stored. Routing packets to a geographic destination location was first presented in [7] with Cartesian Routing, which uses latitude-based and longitude-based addresses. In our proposed algorithm, the ticket-partition is based on geo-location. Specifically, the 2-D broadcast space is partitioned into a set of small grids.

3. Multiple Packet Broadcasting

In this section, we will first explain the area division method. Then, we will present the two steps of our scheme and give an example to explain the whole process.

3.1. System Model

Due to the characteristics of DTNs and the limited bandwidth, we assume that in each contact, the forwarding node can forward limited packets to a receiving node. Assume there are n nodes in the network. Initially, there is one source node which holds m packets. The area of the network will be equally divided into g grids generated by partitioning the 2-D broadcast space along both dimensions. Each packet will be associated with t number of tickets, and each grid has t/g number of tickets. Each node a is associated with a *global active level* G_a and g number of *local active levels* $L_a(i)$ for grid i ($i \in (1, 2, \ldots g)$). Each packet will also be associated with a *priority value* P to prioritize packets and to help select the highest priority packet to be forwarded.

Fig. 1 is an example of our protocol. In Fig. 1(a), the square node is the source node, which takes two packets initially. When it encounters a neighbor node, it will decide which packet will be forwarded. Circle nodes represent nodes that hold packet 1, star nodes are nodes that hold packet 2, and diamond nodes represent nodes that have no packets. After a while, both packets will be broadcasted to all of the nodes, as shown in Fig. 1(d).

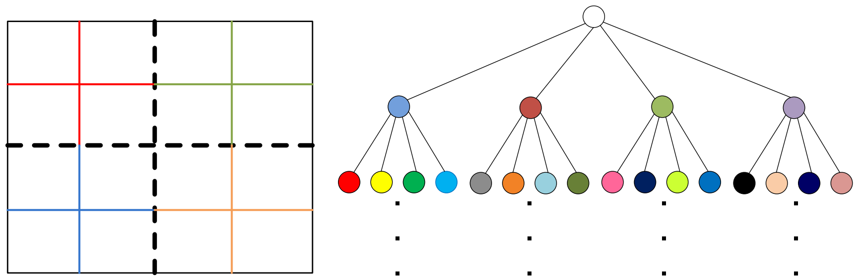
3.2. Quad-grid Division and Ticket Distribution in 2-D Space

Given a 2-D space network, we first divide the area into multiple grids. As shown in Figs. 2 and 1(a), the area will be recursively divided into 4 small grids. Each node belongs to only one grid. This idea can use a quadtree to be explained as Fig. 2(b). Tickets are assigned to grids, k copies for each. k depends on the number of nodes in the 2-D space and the number of grids.

As the recursion gets deeper, the number of tickets also increases. To reduce overhead in piggybacking these tickets, we can judiciously control the depth of the partition to balance cost (in maintaining tickets) and efficiency (in maintaining a certain level of ticket granularity).

3.3. Packet Selection

The first step of the proposed scheme is packet selection. When node a, with m number of packets, has a contact with node b, node a will select the highest priority packet to forward. There are three parameters affecting the priority of the packet. (1) *Tickets (C)*: the number of tickets this packet holds. The more tickets the packet holds, the fewer the nodes in the network already received this packet. Hence, the packet with more tickets will have higher priority. (2) *Time (T)*: the time that this packet traveled in the



(a) Quad-grid partition (b) Quadtree

Figure 2: Area division.

network. If a packet has been traveling in the network for a long amount of time, it is likely that it has already been forwarded to other nodes. Hence, we propose *first in first out* (FIFO) for packet selection based on the parameter *time* in our simulation. (3) *Hop-count (H)*: the number of times the packet has been forwarded. The larger the hop-count the packet has, the more of a chance other nodes have to already be covered. Thus, we assign the packet which has a larger hop-count and a lower priority.

3.4. Relay Node Selection

The second step is to select a good relay node. A good relay node is the node that can cover more grids and has a higher frequency of contact with other nodes in the network.

There are two parameters to measure the node's value. (1) Global active level (G): a priori knowledge or estimation of the total number of contacts within the network in a given period; (2) Local active level (L): a priori knowledge or estimation of the number of contacts this node has with other nodes in this grid in a given period.

In our simulation, the given period to calculate the active level is the length of the whole period before the current contact. Hence, the active level is based on the historical information. The highest priority packet selected in the previous step will be forwarded to node b. Whether node b has the ability to forward this packet is based on the tickets. The ticket partition strategy is explained in the following.

First, node a and node b will exchange their global active level G_a and G_b. Node a only forwards the tickets to node b with a higher global active level (G_b) than its own (G_a). This approach does not need global knowledge. Each

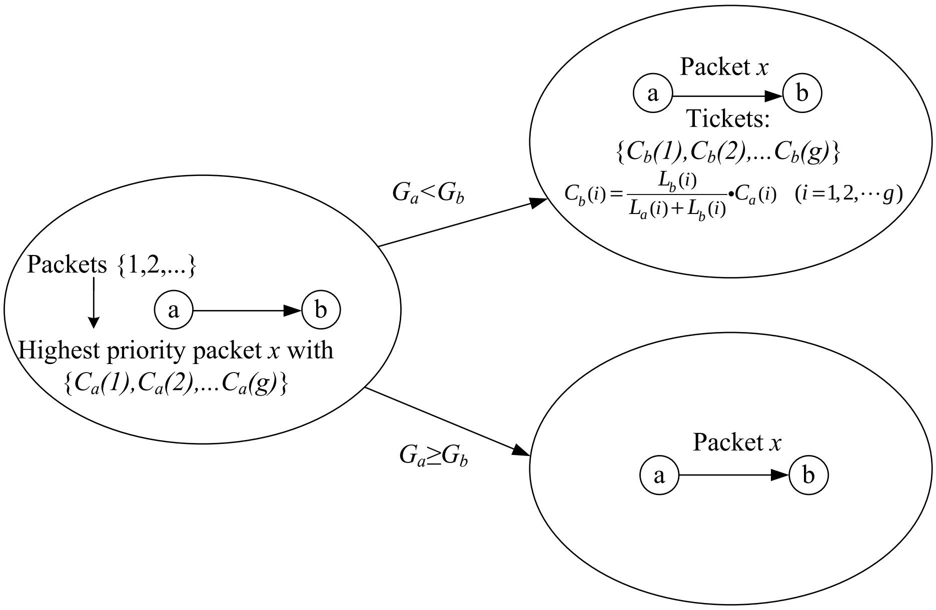


Figure 3: Ticket-based multiple packet DTN broadcasting.

node decides whether it should or should not forward the message by itself. This is suitable for a distributed environment such as DTNs. In addition, node a will raise its own level to the higher level of node b. This idea is based on *delegation forwarding* [5], which means the packet holder will just assign the tickets to the relay node which has the highest global active level it has ever seen.

Then, we use the local active levels to decide how many tickets for each grid should be assigned to the receiving node.

$$C_b(i) = \frac{L_b(i)}{L_a(i)+L_b(i)} \cdot C_a(i) \ (i = 1, 2, \cdots, g),$$

where $C_a(i)$ is the number of tickets for the selected packet x, held by node a for grid i, and $L_a(i)$ is the local active level of node a for grid i. At the same time, we will leave $\frac{L_a(i)}{L_a(i)+L_b(i)} \cdot C_a(i)$ number of tickets for grid i in node a.

The whole process can be explained by Algorithm 1. Fig. 3 illustrates our entire solution. When node a and node b have a contact, they will first exchange their holding packet lists. Then, node a will sort the packets which are not in node b's list based on the tickets that the packet is holding. Packet x is the highest priority packet that can be chosen to be forwarded. After

Algorithm 1 Multiple packet broadcasting in DTNs

1: When node a with global active level G_a encounters node b with G_b.
2: Local active level for grid i, $(i = 1, 2, \cdots, g)$, $L_a(i)$ and $L_b(i)$.
3: Node a selects the highest priority packet x with $C_a(i)$ tickets to be forwarded.
4: **if** $G_a < G_b$ **then**
5: Node b will be the relay for packet x.
6: $G_a \leftarrow G_b$
7: $C_b(i) : \frac{L_b(i)}{L_a(i)+L_b(i)} \cdot C_a(i)$ for node b
8: $C'_a(i) : \frac{L_a(i)}{L_a(i)+L_b(i)} \cdot C_a(i)$ for node a
9: **else**
10: Node b will just receive packets without tickets
11: **end if**

that, these two nodes will compare their global active levels. If $G_a < G_b$, node a will duplicate packet x with some tickets, which will be based on the local active level, and be forwarded to node b. Otherwise, node b will just receive packet x without any tickets, which means node b cannot forward the packet to other nodes later.

4. Simulation

In this section, the metrics, which are calculated in our simulation, are *average latency* and *useless contacts*.

1. *Average latency*: the average duration of multiple packets between the time that they enter the network and the time that they finish broadcasting to all of the nodes within the network.

2. *Useless contacts*: the number of contacts that have no packet forwarded when two nodes have a contact.

4.1. Simulation Methods and Setting

4.1.1. Synthetic traces

We used synthetic traces with GPS information for the nodes' mobility. Based on the GPS information of each node, we assign each node to one grid. We use Levy walks and the community-based mobility model as these nodes' mobility patterns. Each time two nodes make contact with each other, we give a contact time and a GPS address. In the Levy walks mobility pattern, we use TLW MATLAB [1] to generate the human mobility model. In the community-based mobility model, we use the movement patterns generator [2], which is implemented by the University of Cambridge's computer laboratory, to generate the nodes' mobility patterns.

For the average latency comparison, we set up a 100-node environment. The initial number of packets in the source node will be set to 2 and 10. We also set up the delivery ratio [1] as 100%, 90%, and 80%. We compare the performance of the schemes using the tickets, time, hop-count, or random [2], as a primary key for packet priority ranking.

For the useless contacts comparison, we also set up a 100-node environment. The initial number of packets in the source node are set to 2, 4, 6, 8, and 10 respectively. We will compare the useless contacts using tickets, time, or hop-count for packet priority ranking. In the relay node selection step, we will also compare our ticket-based scheme with the no ticket assignment scheme, when the packets are ordering during the whole process.

4.1.2. Real traces

We use NCSU's human mobility traces [16] in our simulation. These traces are collected human mobility traces from five different sites - two university campuses (NCSU and KAIST), New York City, Disney World (Orlando), and the North Carolina state fair. We use the NCSU campus trace and the North Carolina state fair trace to evaluate our schemes.

For the average latency comparison, the initial number of packets in the source node will be set to 2 and 4. [3] For the NCSU campus trace, we set up the delivery ratio as 85%, 80%, and 75% [4]. For the North Carolina state fair trace, we set up the delivery ratio as 100%, 90%, and 80%.

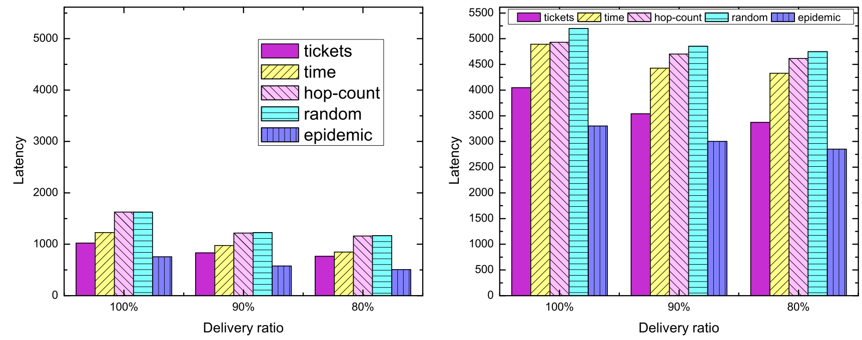
For the useless contacts comparison, the initial number of packets in the source node are set to 2, 3, and 4 respectively. We will compare the useless contacts using tickets, time, or hop-count for packet priority ranking and epidemic routing scheme. In the relay node selection step, we will also

[1] Delivery ratio: the rate of the packets received by all the nodes in the network.

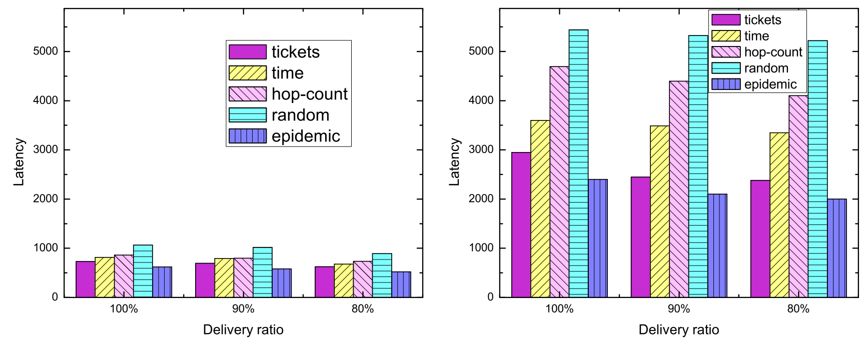
[2] When there are multiple packets in the node's list, we will randomly pick one to forward.

[3] Because of the limited contact times, a large number of packets will reduce the delivery ratio.

[4] In the NCSU campus trace, it is hard to reach 100% delivery ratio.



(a) 2 packets (b) 10 packets



(c) 2 packets (d) 10 packets

Figure 4: Average latency comparisons in Levy walks model ((a) and (b)) and community-based mobility model ((c) and (d)).

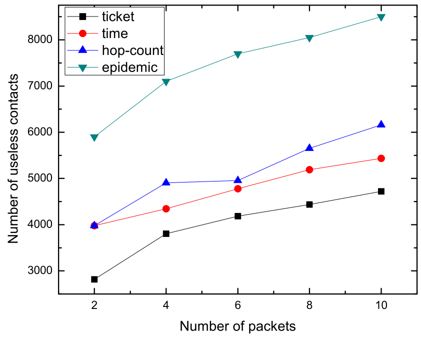
compare our ticket-based scheme with the no ticket assignment scheme when the priority of the packets is not changing during the whole process.

4.2. Simulation Results for Synthetic Traces

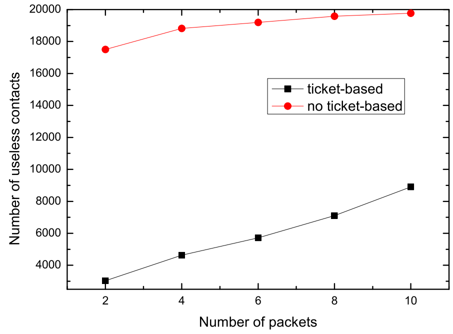
4.2.1. Average latency comparison

We compare the latency in 4 parameters: tickets, time, hop-count, or random, to prioritize packets, as shown in Fig. 4. The results of the epidemic routing scheme are also including in these figures. Both Levy walks and the community-based mobility models show that the ticket-based scheme has the shortest latency out of all three delivery ratios. The schemes that control the packet priority ranking are all better than the random scheme.

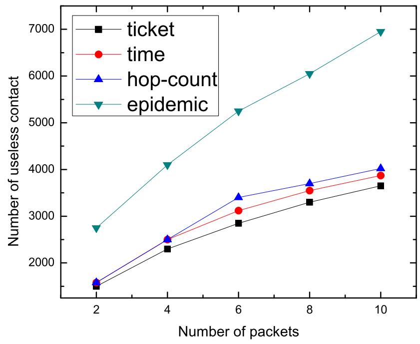
In the Levy walks model, the ticket-based scheme has about 16.7% shorter latency than the time-based schemes, as shown in Figs. 4(a) and 4(b). In



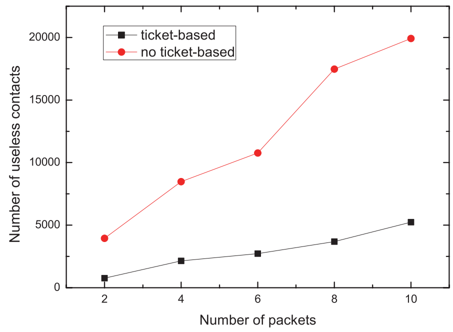
(a) Packet selection



(b) Relay node selection



(c) Packet selection



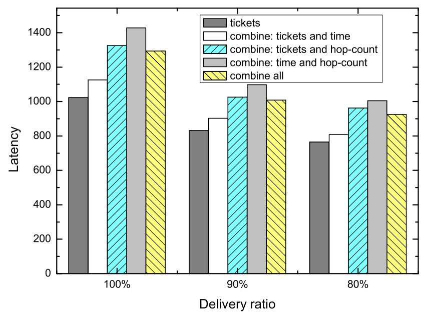
(d) Relay node selection

Figure 5: Useless contacts comparison in synthetic traces: Levy walks model ((a) and (b)) and community-based mobility model ((c) and (d)).

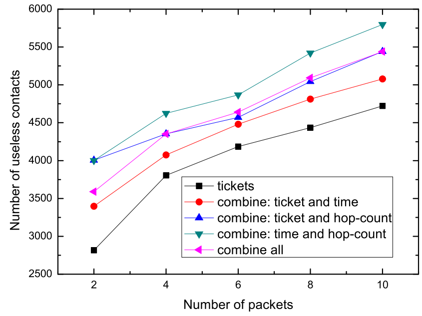
the community-based mobility model, the ticket-based scheme saves 22% of time compared with the time-based scheme, as shown in Figs. 4(c) and 4(d). That's because the ticket-based scheme not only has the global information about the packets, but also considers the mobility patterns, which we think is Levy walks or community-based mobility in this paper. Hence, ticket-based schemes have the best performance.

In both Levy walks and community-based mobility models, the epidemic routing scheme can reduce the latency by about 20% compared with ticket-based scheme in both 2 and 10 packets cases, as shown in in Fig. 4.

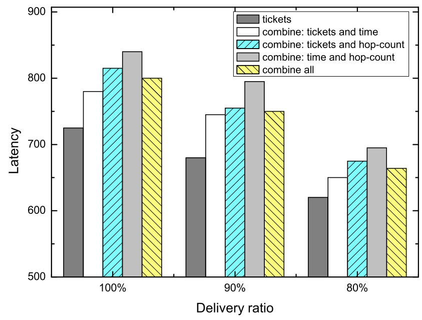
We also want to see the performance of the scheme that combines tickets, time, and hop-count together to calculate the packet priority. In the combined schemes, we use the equation below to calculate the packet priority P:



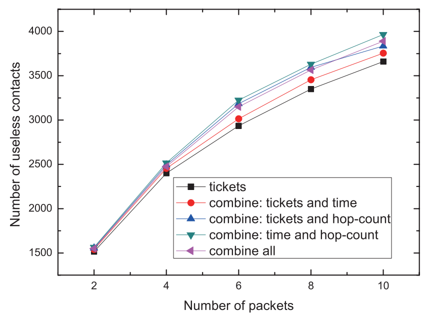
(a) Latency



(b) Useless contacts



(c) Latency



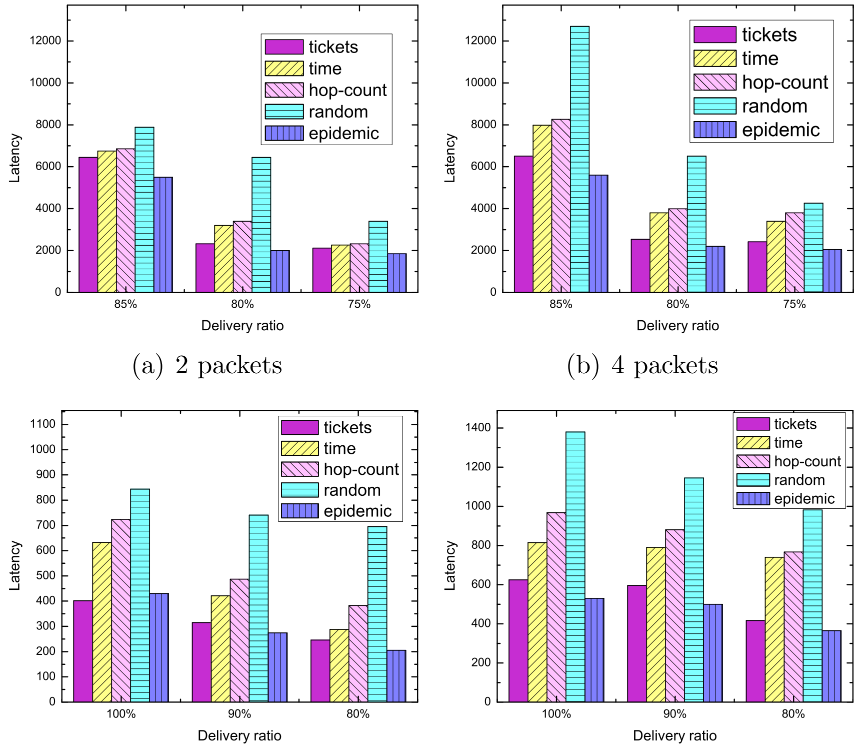
(d) Useless contacts

Figure 6: Comparison of ticket-based scheme and combined scheme in synthetic traces: Levy walks model ((a) and (b)) and community-based mobility model ((c) and (d)).

$$P = \alpha \cdot C - \beta \cdot T - \gamma \cdot H, \tag{1}$$

where C is the number of tickets, T is the time, and H is the hop-count. α, β, and γ are constant parameters combining weight and scaling factors, and $\alpha + \beta + \gamma$ should be 1. For example, when using ticket and time as a combined scheme, $\alpha = \beta = 1/2$, $\gamma = 0$, and the combined three parameters, $\alpha = \beta = \gamma = 1/3$.

We compare our ticket-based scheme with 4 types of combined schemes, as shown in Figs. 6(a) and 6(c). We can see that the combined schemes cannot improve the performance in synthetic mobility models. Hence, we do not discuss combined schemes further.



(a) 2 packets (b) 4 packets

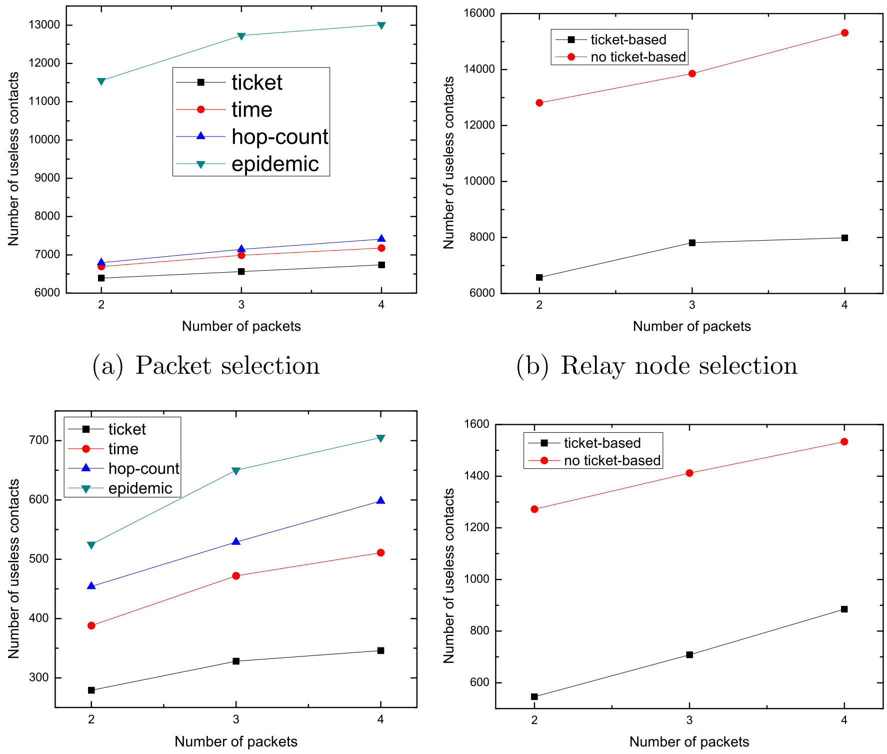
(c) 2 packets (d) 4 packets

Figure 7: Average latency comparisons in the NCSU trace ((a) and (b)) and the North Carolina state fair trace ((c) and (d)).

4.2.2. Useless contacts comparison

In Figs. 5(a) and 5(c), when comparing three parameters for packet priority ranking, we can see that using tickets as the primary key is better than considering time or hop-count. Our ticket-based scheme has a smaller number of useless contacts when there are more packets in the source node initially. When the density of the network is higher, our ticket-based scheme performs better. In the Levy walks model, the ticket-based scheme decreases useless contacts by about 40%, shown in Fig. 5(a). In Fig. 5(c), the ticket-based scheme reduces useless contacts by about 35%. In Figs. 5(a) and 5(c), we find that epidemic routing generates the number of useless contacts dramatically compared with the ticket-based scheme by about 100%, both in Levy walks and community-based mobility models.

We compare the ticket-based scheme with the no ticket-based scheme



(a) Packet selection (b) Relay node selection

(c) Packet selection (d) Relay node selection

Figure 8: Useless contacts comparison in real traces: the NCSU trace ((a) and (b)) and the North Carolina state fair trace ((c) and (d)).

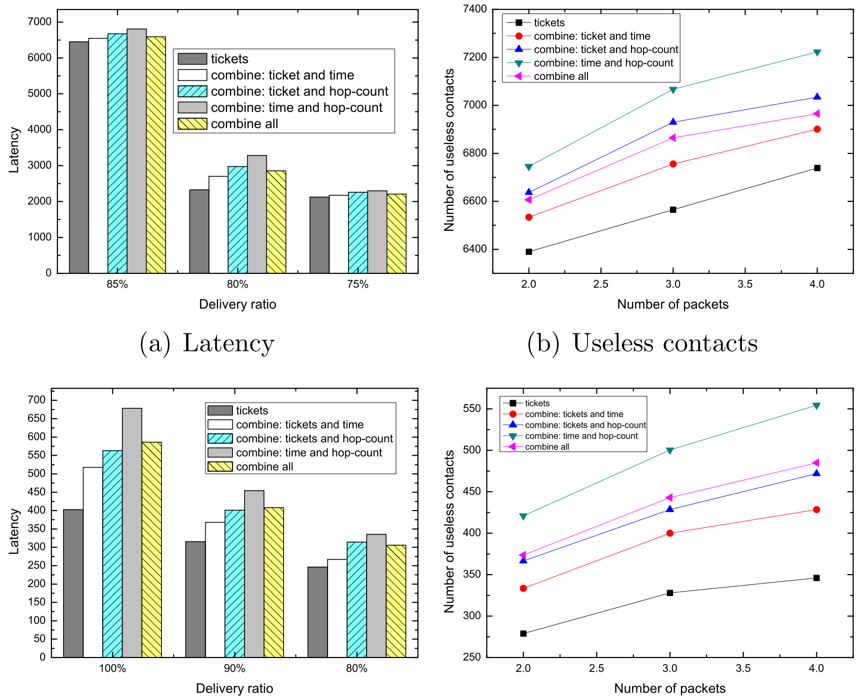
in relay node selection, as shown in Figs. 5(b) and 5(d). Obviously, the ticket-based scheme has a much smaller number of useless contacts in all conditions.

We also use Equation 1 to compare our ticket-based scheme with the combined schemes, both in the Levy walks and the community-based mobility models. We find that the combined schemes cannot reduce the useless contacts, as shown in Figs. 6(b) and 6(d). Hence, we will not compare the combined schemes with our schemes in this section.

4.3. Simulation Results for Real Traces

4.3.1. Average latency comparison

We compare the latency in 4 parameters: tickets, time, hop-count, or random, as a primary key for packet priority ranking, as shown in Fig. 7.



(a) Latency (b) Useless contacts

(c) Latency (d) Useless contacts

Figure 9: Comparison of the ticket-based scheme and the combined schemes in real traces: the NCSU trace ((a) and (b)) and the North Carolina state fair trace ((c) and (d)).

The results of the epidemic routing scheme also show in Fig. 7. Fig. 7 shows that the ticket-based scheme has the shortest latency out of all three delivery ratios. The ticket-based scheme reduces the latency by almost half compared to the random scheme. The schemes using some parameters to control the packet priority ranking are all better than the random scheme. Both the NCSU trace and the North Carolina state fair trace show that the ticket-based scheme will slightly increase the latency compared with the epidemic scheme.

The ticket-based schemes have about 30% shorter latency than the time-based schemes, as shown in Fig. 7. We also find that our ticket-based scheme performs better when there are more packets initially. That's because more packets need more of an efficient packet priority ranking scheme.

We also use Equation 1 as the combined schemes to sort the packets. From Figs. 9(a) and 9(c), we find that our ticket-based scheme is better than the combined schemes. Hence, we do not use the combined schemes to compare the performance in real traces.

4.3.2. Useless contacts comparison

In Figs. 8(a) and 8(c), when comparing three parameters for packet priority ranking, we can see that using tickets as the primary key is better than considering time or hop-count. In Fig. 8(a), the time-based scheme gives a similar performance when compared to the hop-count-based scheme, and the ticket-based scheme reduces useless contacts by about 16.5% when compared to the other two schemes. In Fig. 8(c), in the North Carolina state fair trace, the ticket-based scheme has a 45.5% smaller number of useless contacts than the other two schemes. Our ticket-based scheme has a smaller number of useless contacts when there is a larger number of packets in the source node initially. Using epidemic routing will generate the number of useless contacts dramatically in real traces.

We compare the ticket-based scheme with the no ticket-based scheme in relay node selection, as shown in Figs. 8(b) and 8(d). Obviously, our scheme has a much smaller number of useless contacts under all conditions.

Using Equation 1 as the combined schemes to compare with our ticket-based scheme, we find that the combined schemes cannot improve the performance, as in Figs. 9(b) and 9(d). Hence, we will not use the combined schemes in the useless contacts comparison.

4.4. Summary of Simulation

Although epidemic routing can slightly reduce the latency compared with the ticket-based scheme, it generates the number of useless contacts dramatically. In both synthetic and real traces, our ticket-based scheme performs well not only in the packet selection stage, but also in the relay node selection stage. The ticket-based scheme can reduce the latency, while at the same time reduce the number of useless contacts, which can have an impact on reducing the broadcasting cost. We also find that our ticket-based scheme performs better when there are more packets initially. That is because more packets require a more efficient packet priority ranking scheme. The ticket-based scheme not only has the global information about the packets, but also considers the mobility patterns. Hence, the ticket-based schemes have the best performance. In the packet selection stage, using time as the primary parameter is better than using hop-count, to control the packet priority. The time-based scheme has global information due to us knowing the total time that the packet has traveled in the network, while the hop-count-based scheme just knows the neighbors' information. Hence, using the time-based scheme will have shorter latency and fewer useless contacts compared to the hop-count-based scheme. Future research can benefit from our results by developing specific applications based on our proposed schemes in DTN broadcasting.

5. Conclusion

In this paper, we focused on developing a ticket-based multiple packet broadcasting scheme in DTNs. Based on the human mobility pattern, which is proven to follow Levy walks or community-based mobility models in recent research, we use the quad-grid division scheme to divide the whole network into small grids, which can help the message to be forwarded quickly in the same grid. Our ticket-based scheme has two steps: packet selection and relay node selection, with the objective of reaching all nodes in the network quickly while minimizing the total number of useless contacts. We proposed the use of the number of tickets the node currently holds to decide the packet priority value. In the relay node selection step, we use nodes' global active level and local active level to determine whether the tickets of the selection packet should be assigned to the next relay node. We compared our ticket-based scheme with the time-based and hop-count-based schemes. Synthetic and real trace-driven results showed that our ticket-based scheme has the best performance, resulting in the shortest latency and the smallest number of useless contacts. We believe that the results obtained from this paper present the first step in exploiting the ticket-based scheme in DTN broadcasting.

Acknowledgments

This research was supported in part by NSF grants ECCS 1128209, CNS 1065444, CCF 1028167, CNS 0948184, and CCF 0830289.

References

[1] NCSU networking research lab: Human mobility models. Downloaded from http://research.csc.ncsu.edu/netsrv/?q=content/human-mobility-models-download-tlw-slaw.

[2] University of Cambridge computer laboratory: Social network founded mobility models for ad hoc network research. Downloaded from http://www.cl.cam.ac.uk/research/srg/netos/ mobilitymodels/.

[3] UUMAP, "UUCP Mapping Project". software available at ftp.uu.net/uumap/, 1985.

[4] D. Brockmann, L. Hufnagel, and T. Geisel. The scaling laws of human travel. *Nature*, 439:462–465, 2006.

[5] V. Erramilli, M. Crovella, A. Chaintreau, and C. Diot. Delegation forwarding. In *Proc. of ACM MobiHoc*, pages 251–260, 2008.

[6] K. Fall. A delay-tolerant network architecture for challenged Internets. In *Proc. of ACM SIGCOMM*, pages 27–34, 2003.

[7] G. Finn. Routing and addressing problems in large metropolitan-scale internetwork. *lSI Research Report ISI/RR-87-180, University of Southern California*, 1987.

[8] M. C. Gonzalez, C. A. Hidalgo, and A.-L. Barabasi. Understanding individual human mobility patterns. *Nature*, 453:779–782, 2008.

[9] A. Goundan, E. Coe, and C. Raghavendra. Efficient broadcasting in delay tolerant networks. In *Proc. of IEEE GLOBECOM*, 2008.

[10] L. Hu and L. Dittmann. Heterogeneous community-based mobility model for human opportunistic network. In *Proc. of IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, volume 0, pages 465–470, 2009.

[11] G. Karlsson, V. Lenders, and M. May. Delay-tolerant broadcasting. In *Proc. of the ACM SIGCOMM workshop on Challenged networks (CHANTS)*, pages 197–204, 2006.

[12] M. Musolesi and C. Mascolo. A community based mobility model for ad hoc network research. In *Proc. of ACM REALMAN*, pages 31–38, 2006.

[13] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu. The broadcast storm problem in a mobile ad hoc network. In *Proc. of ACM MobiCom*, pages 151–162, 1999.

[14] R. S. Peterson and E. G. Sirer. Antfarm: efficient content distribution with managed swarms. In *Proc. of the 6th USENIX NSDI*, 2009.

[15] I. Rhee, M. Shin, S. Hong, K. Lee, and S. Chong. On the levy-walk nature of human mobility. In *Proc. of IEEE Infocom*, pages 924 –932, 2008.

[16] I. Rhee, M. Shin, S. Hong, K. Lee, S. Kim, and S. Chong. CRAWDAD data set ncsu/mobilitymodels (v. 2009-07-23). Downloaded from http://crawdad.cs.dartmouth.edu/ncsu/mobilitymodels.

[17] T. Spyropoulos, K. Psounis, and C. S. Raghavendra. Spray and wait: an efficient routing scheme for intermittently connected mobile networks. In *Proc. of ACM SIGCOMM WDTN*, pages 252–259, 2005.

[18] K. Steinhaeuser and N. V. Chawla. Community detection in a large real-world social network. *Social Computing, Behavioral Modeling, and Prediction, Springer*, 2008.

[19] G. S. Thakur, A. Helmy, and W.-J. Hsu. Similarity analysis and modeling in mobile societies: the missing link. In *Proc. of the 5th ACM workshop on Challenged networks (CHANTS)*, pages 13–20, 2010.

[20] G. M. Viswanathan, V. Afanasyev, S. V. Buldyrev, E. J. Murphy, P. A. Prince, and H. E. Stanley. Levy flights search patterns of wandering albatrosses. *Nature*, 381:413–415, 1996.

[21] J. Wu and F. Dai. Broadcasting in ad hoc networks based on self-pruning. In *Proc. of IEEE Infocom*, volume 3, pages 2240 – 2250, 2003.

[22] J. Wu and Y. Wang. A non-replication multicasting scheme in delay tolerant networks. In *Proc. of IEEE MASS*, 2010.

[23] J. Wu and Y. Wang. Social feature-based multi-path routing in delay tolerant networks. In *Proc. of IEEE Infocom*, 2012.

[24] W. Zhao, M. Ammar, and E. Zegura. Multicasting in delay tolerant networks: semantic models and routing algorithms. In *Proc. of ACM SIGCOMM WDTN*, pages 268–275, 2005.