Asymmetric Spray and Multi-forwarding for Delay Tolerant Networks

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Abstract. The framework of Delay Tolerant Networks (DTNs) has received an extensive attention from academic community because of its application ranging from Wireless Sensor Networks (WSNs) to interplanetary networks. It has a promising future in military affairs, scientific research and exploration. Due to the characteristic of long delay, intermittent connectivity and limited network resource, the traditional routing algorithms do not perform well in DTNs. In this paper, our proposed algorithm is based on an asymmetric spray mechanism combining with the concept of message classes. For each message class, a corresponding forwarding queue is designed and these queues are scheduled according to their priorities. Together with other designed assistant functions, our proposed algorithm outperforms other state of the art algorithms in terms of delivery ratio, overhead ratio, average latency as well as energy consumption.

Keywords: Delay Tolerant Networks, Routing Algorithms.

1 Introduction

The TCP/IP protocol has played an important role in the development of Internet. Specifically, it works under the assumptions such as contemporaneously end-to-end connectivity, relatively short round trip time and low error rate. However, this is impossible for some challenge networks including wildlife tracking, Vehicle Ad hoc Networks (VANETs), interplanetary networks, military networks, pocket switched networks, underwater networks and rural Internet. Generally, these are intermittently connected because of the sparse network density or high mobility.

Delay Tolerant Networks (DTNs) [1] are designed to cope with these challenges. It makes use of scheduled, predicted and opportunistic connectivity, forms a store and forward overlay network to provide custody based message oriented transfer. Routing is the main challenge in DTNs since its characteristic prevents the traditional routing techniques from working effectively. Up to now, many existing routing algorithms in DTNs have been proposed to enable message delivery in such challenge environment. Delivery ratio as the main performance objective is always taken into account. However, the performance of these algorithms creates more contention in terms of the network resource and more energy consumption even if they can achieve a high delivery ratio.

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In general, the routing protocols must make a tradeoff between maximizing the message delivery ratio and minimizing resource consumption. On one hand, the ideal approach is to use the single copy for successful delivery. However on the other hand, the effective way to maximize the message delivery is to enlarge the number of message copies in the networks. Therefore, the feasible approach to reduce the overhead but maintain the high delivery ratio is to intelligently replicate the message.

The main contribution of this paper is the design of an algorithm to achieve high delivery ratio with low overhead as well as the relatively less latency and energy consumption. Our proposed algorithm mainly implements an asymmetric spray approach to promote the message dissemination to the intermediate node which more likely encounters the destined node with the guarantee that the message can be delivered before its expiration time. Based on the characteristic of messages, we classify them into three classes. For each class, a corresponding forwarding queue is proposed. In particular these queues are dynamically scheduled according to the defined priorities.

In the following section, we briefly review the taxonomy of unicast routing algorithms in DTNs, then in section 3 we present our algorithm. The simulation results are presented in section 4 followed by the conclusion section.

2 Related Work

Excluding the assistance of additional infrastructure, the taxonomy of unicast routing algorithms in DTNs are mainly classified into three families, which are single copy utility forwarding, multi copy naive replication and hybrid families.

2.1 Single Copy Utility Forwarding Family

The algorithms in this family use only one copy, which means the message carrier does not keep the copy of the forwarded message after the successful transfer. The earlier stage algorithms in [2] focus on the delay of each link state and requires a global information to route the message based on the shortest path. Social networks as a new research area proposed in recent years utilize the encounter relationship of pairwise nodes [3]. Other parameters such as energy, movement speed, network density and location can also be used for routing decision. For example the Context Aware Routing (CAR) [4] utilizes the residual energy, variation of network topology for the DTNs based routing algorithm. In particular, if the contemporaneously end-to-end connectivity is currently available, then the routing function shifts to the traditional routing protocol such as Destination-Sequenced Distance Vector (DSDV) to forward the message, otherwise it adopts the context information to select the candidate node for the DTNs based routing algorithm. Nevertheless, these routing algorithms do not work effectively in the sparse scenario where the message lifetime is quite limited since the only one copy can not guarantee the effective delivery.

2.2 Multi Copy Naive Replication Family

The simplest algorithm is Direct Delivery [5], which only replicates the message if the current carrier encounters the destination. It is considered as a degraded naive replication based algorithm. The Epidemic as the earliest multi-copy based algorithm is proposed in [6]. In detail, each node does not implement the routing decision but just replicates the message to encountered node unless it already carries this message. Provided that the buffer resource and bandwidth is large enough, Epidemic theoretically guarantees the lowest latency for maximum delivery ratio. Nevertheless, the contention due to the limited resource in reality is the main limitation of the scalability. The Spray-and-Wait [7] combines the diffusion speed of Epidemic with the simplicity and thriftiness of Direct Delivery. For each message, an initial number of copy tickets is defined to limit the number of replication, which enables them to be sprayed at each encounter opportunity with the guarantee at least one of them can be delivered. Intermediate node carrying the message of which the copy ticket is one performs the Direct Delivery.

2.3 Hybrid Family

The algorithms in this family utilize the advantage of single copy utility forwarding and naive replication based algorithms, which aims to improve the overhead ratio as well as acceptable delivery ratio. The Prophet [8] integrates the property of replication and prediction based forwarding. The current carrier replicates the message to the candidate node with higher encounter probability. In addition, it also uses the transitivity to enhance the congestion avoidance. The core concept of the MaxProp [9] protocol is a ranked list of the carried messages based on a cost for each destination. The cost is an estimate of virtual end to end route failure possibility, initially the possibility for each pair of nodes is uniformly distributed and updated according to the incremental averaging. Two thresholds are defined to calculate the drop and transmission priority for message. In addition, MaxProp uses acknowledgment to inform the intermediate node to clear out the existing copies of the delivered messages. The Spray-and-Focus [10] aims to optimize the Spray-and-Wait in the wait phase. Instead, it forwards the message with single copy to the candidate node with transitive recent encounter time rather than just wait. Nevertheless, its performance is strongly affected by the specific mobility characteristic.

3 Our Proposed Algorithm

The overall function flowchart of the proposed algorithm is illustrated in Fig.1 and its specific functions are introduced in the following subsections.

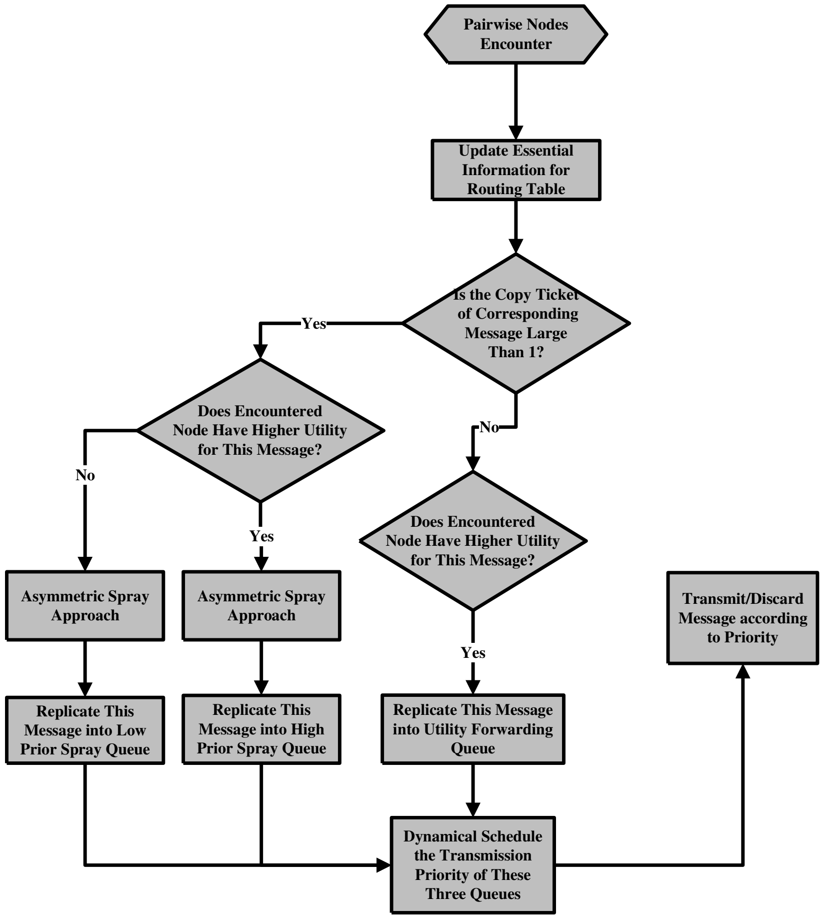


Fig. 1. Function Flowchart

3.1 Definition of the Utility Metric

Traditionally, the main problem of designing an efficient routing algorithm in DTNs is how to obtain the network topology information. Due to the limited property of device, it is difficult to obtain this information by the broadcasting mechanism used in MANETs. Some techniques in related work assume that the partial history information can predict the future encounter opportunity. However, it does not comprehensively take into account the mobility pattern. Assuming the future mobility pattern is known in advance is unreasonable in DTNs, thus our algorithm is designed based on these assumptions but makes use of the history information.

Considering the mobility factor, we address three conventional metrics between pairwise encountered nodes N_i and N_j, which are history encounter count $C_{i,j}$, history encounter duration $D_{i,j}$ and history inter meeting time $I_{i,j}$ where $i, j \in S$ and S is the total number of nodes in the network. We assume DTN node does not strictly move with a cyclic mobility pattern. To this end, we propose an cumulative formula to smooth the effect of large variation within the number of encounters, where the utility $U_{i,j}$ is defined as:

$$U_{i,j} = \frac{\sum_{k=2}^{C_{i,j}} (\frac{D_{i,j}^{k-1}}{I_{i,j}^{k}})}{(C_{i,j} - 1)} \tag{1}$$

In detail, $D_{i,j}^{k-1}$ is the encounter duration before the k^{th} encounter and it is valid after the first encounter. With the time elapsing this property is useful since the node experiences a large number of encounters is more likely to successfully route the message to the final destination than those who have infrequent encounters.

Normally, for each encounter opportunity the pairwise nodes would update their local routing information which contains a set of $U_{i,j}$ for the nodes they encountered before. Nevertheless, to estimate the delivery potential based on the local knowledge is unreasonable since it ignores the factor of its history encountered nodes.

Therefore, we propose an approach to help each node to improve this limitation. For instance, when pairwise nodes encounter, firstly both of them would calculate and update their $U_{i,j}$ for each other. Afterwards, they would also add their local routing information to each other for the purpose of extending the knowledge. To this end, they can obtain the knowledge from their neighbors' history encounter information. Based on the above analysis, an improved utility $U'_{i,j}$ is proposed:

$$U'_{c,d} = \frac{\sum_{k=1}^{n} U_{c(k),d} + U_{c,d}}{count + 1} \tag{2}$$

where n is the number of history encountered nodes of current carrier c, $c(k)$ is the history encountered node of c, d is the corresponding destination node. In detail, *count* is initialized with zero and increased by one if $c(k)$ contains the $U_{c(k),d}$ for d. Therefore, the local node would obtain an abstract average knowledge for d not only based on itself but also based on the history information from its neighbors by (2). As an example in TABLE 1, the $U'_{6,2}$ based on the view of N_6 is calculated as:

$$U'_{6,2} = \frac{0.6 + 0.3 + 0}{2 + 1} = 0.3 \tag{3}$$

3.2 Asymmetric Spray Approach

Binary Spray-and-Wait as a classic algorithm has been proved and used in many scenarios because of its acceptable high delivery ratio and relatively low overhead ratio. However, it does not take into account the delivery potential of the candidate node. Each node just naively sprays half number of copy tickets to any encountered node. Based on our improved utility defined in the previous

Table 1. Example of Routing Table of N_6

current carrier N_6	$U_{6,1}$	0.4
	$U_{6,5}$	0.2
	$U_{6,4}$	0.0
history encountered N_1 of N_6	$U_{1,6}$	0.4
	$U_{1,2}$	0.6
	$U_{1,4}$	0.3
history encountered N_5 of N_6	$U_{5,2}$	0.3
	$U_{5,8}$	0.1
	$U_{5,6}$	0.2

subsection, we assume that each node has a certain potential to route the message towards its destination. Therefore, on one hand, to equally spray the copy ticket might not be reasonable since to spray the half number of copy tickets to the encountered node with less $U'_{i,j}$ would waste some encounter opportunity. Relatively, on the other hand, to unequally spray the copy ticket without any consideration is also infeasible. To this end, we propose a novel copy ticket spray approach based on binary Spray-and-Wait. For each message M of which the destination is N_d and with T copy tickets carried by N_i, if node N_i has a lower $U'_{i,d}$ for this message destination than $U'_{j,d}$ of the encountered node N_j, N_i sprays more copy ticket of message M to N_j and keeps less copy ticket by itself. The specific process is illustrated in Algorithm 1. Provided that $U'_{i,d}$ is larger than or equal to $U'_{j,d}$, inherently, it is appropriate for the current carrier to keep the original copy ticket until it encounters a better candidate node. Nevertheless, this behavior might result in higher latency since the specific future prediction of mobility is independent of our assumption. As such, the poor candidate node might encounter another better candidate node in the future. Therefore, the current carrier sprays less number of the copy tickets to the encountered node with lower $U'_{j,d}$.

3.3 Multi-forwarding Approach

High Priority Spray Queue ($HPSQ$): Upon the asymmetric spray approach, for each encounter of pairwise nodes, the current carrier N_i will check whether the encountered N_j has a higher improved utility for the destination of the carried message M. Besides, it also checks whether the copy ticket of M is larger than one. If any message M accords with the above two conditions, then N_i replicates M to N_j and pushes it into $HPSQ$. Basically, with the asymmetric spray mechanism, more copy ticket of this message would be sprayed to the candidate node which potentially moves towards the destination for efficient delivery.

Algorithm 1. Asymmetric Spray Approach

Input:

current carrier: N_i
encountered node: N_j
carried messages in N_i: M with its destination N_d and copy ticket T
improved utility for N_d: $U'_{i,d}$, $U'_{j,d}$

Output:

for each M **do**
  if $U'_{i,d} < U'_{j,d}$ **then**
    if $T > 2$ **then**
      N_i sprays M with $math.ceil(\frac{T}{2})+math.round(\frac{U'_{j,d}}{U'_{j,d}+U'_{i,d}})$ to N_j
      N_i keeps M with $math.ceil(\frac{T}{2.0})$-$math.round(\frac{U'_{j,d}}{U'_{j,d}+U'_{i,d}})$
    else
      N_i sprays M with $(\frac{T}{2})$ to N_j
      N_i keeps M with $(\frac{T}{2})$
    end if
  else
    if $T > 2$ **then**
      N_i sprays M with $math.ceil(\frac{T}{2.0})$-$math.round(\frac{U'_{i,d}}{U'_{j,d}+U'_{i,d}})$ to N_j
      N_i keeps M with $math.ceil(\frac{T}{2})+math.round(\frac{U'_{i,d}}{U'_{j,d}+U'_{i,d}})$
    else
      N_i sprays M with $(\frac{T}{2})$ to N_j
      N_i keeps M with $(\frac{T}{2})$
    end if
  end if
end for

Low Priority Spray Queue ($LPSQ$): If the encountered node has a smaller improved utility for the destination than the current carrier, N_i would try its best to spray the copy ticket of all the carried messages to the encountered node even it spays the less copy ticket. These messages with more than one copy ticket are pushed into $LPSQ$.

Utility Forwarding Queue (UFQ): Regarding the message of which the copy ticket is equal to one. It cannot be sprayed but performed as the utility based replication mechanism. For each M destined to N_d carried by N_i, this message is replicated to the encountered node only if $U'_{j,d} > U'_{i,d}$. Accordingly, this message is pushed into the UFQ.

3.4 Scheduling the Priority of Queues

Inherently, the messages with multi-copy ticket in $HPSQ$ and $LPSQ$ should be scheduled prior to the messages with single copy ticket in UFQ. The main reason is that for messages in $HPSQ$ and $LPSQ$, they are sprayed with the dedicated copy ticket. If their life time expire, the worst case is that the messages with

Algorithm 2. Multi-Forwarding Approach

Input:

current carrier: N_i

encountered node: N_j

carried messages in N_i: M with its destination N_d and copy ticket T

improved utility for N_d: $U'_{i,d}$, $U'_{j,d}$

Output:

for each encounter between N_i and N_j **do**
  for each M in N_i **do**
    if N_j already has M **then**
      M is skipped for replication
    else if $U'_{i,d} < U'_{j,d}$ and $T > 1$ **then**
      N_i replicates M according to asymmetric spray and puts into $HPSQ$
    else if $U'_{i,d} < U'_{j,d}$ and $T = 1$ **then**
      N_i replicates M and puts into UFQ
    else if $T > 1$ **then**
      N_i replicates M according to asymmetric spray and puts into $LPSQ$
    end if
  end for
end for

Algorithm 3. Multi-Forwarding Approach

Input:

priority for $HPSQ$: SP_{HPSQ}

priority for $LPSQ$: SP_{LPSQ}

Output:

for each message transfer **do**
  if $SP_{HPSQ} \geq SP_{LPSQ}$ **then**
    schedule $HPSQ$ until $HPSQ$ is empty
      then schedule $LPSQ$ until $LPSQ$ is empty
        then schedule UFQ until UFQ is empty
  else
    schedule $LPSQ$ until $LPSQ$ is empty
      then schedule $HPSQ$ until $HPSQ$ is empty
        then schedule UFQ until UFQ is empty
  end if
end for

maximum copy ticket are cleared out from the buffer space. In this case it might degrade the delivery ratio.

Nevertheless, in order to schedule the priority between $HPSQ$ and $LPSQ$, we define a metric called scheduling priority SP for these two queues.

$$SP = \frac{\sum_{k=1}^{m}[MU(c,d) * MCT]}{m} \tag{4}$$

where m is the number of messages in the queue. After each message transfer, the current carrier will check the current SP of these two queues. To this end, as it is proposed in the DTNs RFC, we classify the messages into three classes which are bulk, normal and expedited. In the meanwhile they are processed according to the specific forwarding policies and scheduled according to their priorities respectively.

3.5 Transmit/Discard Message According to Priority

The main motivation to define the message priority MP is to transmit the most appropriate message at each encounter opportunity. Totally different from the algorithms in traditional networks focus on delay, herein we propose to address the delivery potential of each message based on the view of the corresponding node.

The priority of message in this $HPSQ$ is defined as:

$$MP_{HPSQ} = MU(e, d) * MCT \tag{5}$$

It is based on the view of the encountered node e for the destined node d. In detail, MCT is the message copy ticket and MU is the message utility that is defined as $U'_{e,d}$, therefore these messages are scheduled according to the improved utility based on the view of the encountered node. For example, if encountered node has a higher $U'_{e,d}$ for the destination of M_1 than M_2, then M_1 is allocated with higher priority than M_2 if both of them are sent to this encountered node.

The main difference between the priority of messages in $HPSQ$ and $LPSQ$ is that the messages in $LPSQ$ are scheduled based on $U'_{c,d}$ of the current carrier c and their copy tickets. It is defined as:

$$MP_{LPSQ} = MU(c, d) * MCT \tag{6}$$

For messages with one copy ticket that are processed by UFQ, their priorities are defined as:

$$MP_{UFQ} = \frac{MU(e, d)}{Message\ Lifetime} \tag{7}$$

If the message with higher $MU(e, d)$ but with very limited lifetime, it is regarded to be the emergent message. To this end, as the priority proposed, the message which has high potential to be delivered based on the view of the encountered node e and low lifetime is always guaranteed to exist in the networks, which plays a positive effect on maximizing the delivery ratio.

Normally, the storage is limited in the restricted scenario and accordingly each node can not carry all the messages. Hence a reasonable buffer management function is essential. The carried messages are classified into multi copy ticket based and single copy ticket based, then they are pushed into different bins respectively and discarded according to DP defined as:

$$DP = MU(c, d) * MCT \tag{8}$$

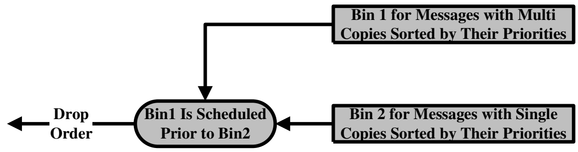


Fig. 2. Drop Priority

Normally the messages in the bin for multi copy ticket based are firstly discarded from the lowest priority. If there are no more messages in this bin, then the messages in the bin for single copy ticket based are discarded from the lowest priority. As it is illustrated in Fig.2, consideration behind this approach is that the message with lowest copy ticket and lowest delivery potential based on the view of current carrier would be more useless since most of its copy has been sprayed to a better candidate node. The messages with one copy ticket are assumed can be delivered with higher potential since they are replicated based on the improved utility. Therefore they are discarded with lowest priority once there are no more messages with multi copy ticket.

To further reduce the redundant transmissions, the destination will generate an acknowledgement of which the size can be ignored compared with the size of message when it successfully receives this message, and this acknowledgement will be flooded to the entire network. Intermediate nodes receive this acknowledgement will check their buffer and discard the message which has been successfully received.

4 Simulation Results

The simulation results are evaluated by Opportunistic Network Environment (ONE) [11]. The scenario area is 15.3 km^2 with 126 mobile nodes configured with different variable speeds. In particular each node has an interest to visit some places rather than randomly select the next point based on the route. We evaluate the Spray-and-Focus (SaF), binary Spray-and-Wait (SaW), Epidemic, Prophet and MaxProp for comparison. Energy function is also integrated into all these algorithms. For the purpose of fairness, the initial number of copies for SaF, SaW is set to 13, which is a recommended value between 10% and 15% nodes in the scenario. We address delivery ratio, overhead ratio, average latency and total residual energy for performance evaluation. Specifically, the delivery ratio and overhead ratio are defined as (9) and (10), total residual energy is measured by the sum of the residual energy of each node.

$$Delivery\ Ratio = \frac{Delivered\ Messages}{Generated\ Messages} \tag{9}$$

$$Overhead\ Ratio = \frac{Relayed\ Messages - Delivered\ Messages}{Number\ of\ Delivered\ Messages} \tag{10}$$

Table 2. Simulation Configurations

Simulation Time	12 Hours
Bandwidth	2Mb/s
Transmission Range	10m
Buffer Size	10MB
Number of Nodes	126
Message Size	200kB-2MB
Message Generation Interval	30s
Message Lifetime	240 Minutes
Initial Energy per Node	850mA/h
Transmission Energy per Node	51.47mA/h
Scanning Energy per Node	38.61mA/h
Scenario Mobility	Helsinki City Model

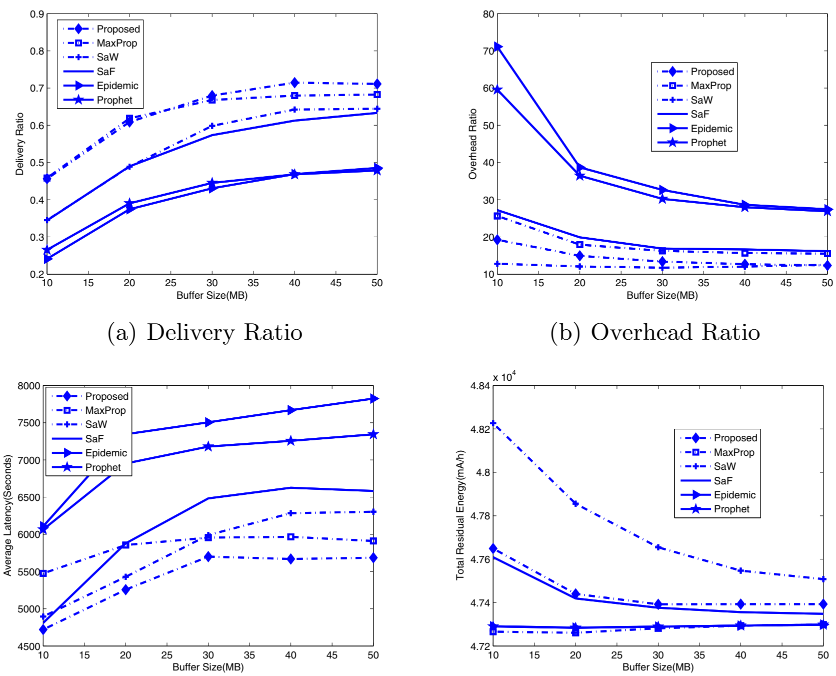
4.1 Effect of Buffer Size

In Fig.3(a), both Epidemic and Prophet achieve the lowest delivery ratio because they do not take into account the utilization of network resource. SaW and SaF limit the number of replication for message, thus the contention regarding the bandwidth and buffer space is alleviated. Compared with MaxProp, which is regarded as a preeminent one for comparison, our algorithm achieves higher delivery ratio particular when the buffer size increases.

With respect to the overhead ratio in Fig.3(b), the overhead ratio of our proposed algorithm is close to SaW if the buffer space is large enough. SaF requires more transmission during the focus phase whereas SaW just implements Direct Delivery in its second phase, this results in a higher overhead ratio of SaF compared with SaW. Even if MaxProp is well designed with buffer management function, our proposed algorithm still outperforms MaxProp.

In Fig.3(c), our proposed algorithm also achieves the lowest average latency compared with other algorithms. Particularly, as we discuss in previous section, our asymmetric spray mechanism plays the important role on this good performance. Another contribution comes from the scheduling approaches, which aims to transmit the most appropriate message at each encounter opportunity.

Energy issue as a new issue has been taken into account in DTNs. According to the result in Fig.3(d), Inherently, our algorithm performs a utility replication approach to route the message if its copy ticket is equal to one, which occupies more network resource and might abort some messages due to the mobility factor. Therefore, it requires the retransmission for the messages which have been aborted, then it consumes more energy than SaW and relatively similar energy as SaF.



(a) Delivery Ratio (b) Overhead Ratio

(c) Average Latency (d) Total Residual Energy

Fig. 3. Effect of Buffer Size

4.2 Effect of Message Lifetime

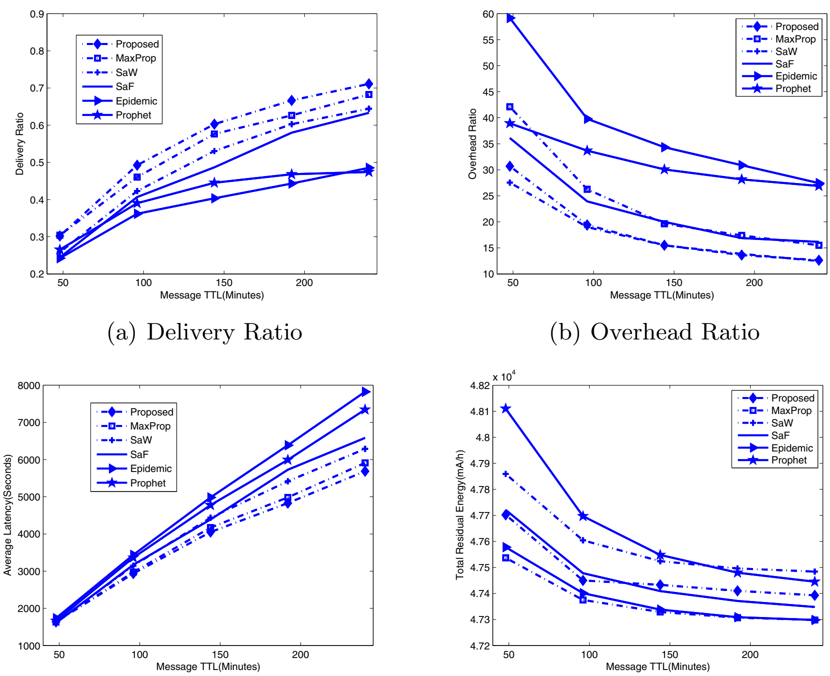
In this section, we fix the buffer size as 50MB but vary the value of message lifetime.

When the message TTL increases in Fig.4(a), our algorithm still outperforms other algorithms. MaxProp with a dedicated buffer management also performs well compared with SaF and SaW since they are not designed with any buffer management function. Due to the limited resource, Epidemic and Prophet perform worse.

The inherent characteristic of our algorithm determines its overhead would be higher than SaW in Fig.4(b). However the difference is quite close if the message TTL is increased, this is because the asymmetric spray approach works significantly since it can spray the message to the candidate node before the expiration time.

With respect to the average latency in Fig.4(c), our algorithm achieves the lowest latency, which is similar to the result affected by the buffer size.

Because of the large message lifetime, the messages in the buffer space might be discarded in case of the replication algorithms. Thus the current carrier would require more transmission for the messages which have been cleared from the buffer, which results in more energy consumption. According to the result in



(a) Delivery Ratio

(b) Overhead Ratio

(c) Average Latency

(d) Total Residual Energy

Fig. 4. Effect of Message Lifetime

the Fig.4(d), based on the the overall performance, SaW and SaF consume less energy since they adopt less number of replication. Relatively, Prophet does not achieve an acceptable delivery ratio even if it consumes the least energy. Our algorithm balances the energy consumption and the deliver ratio, thus it is energy efficient.

5 Conclusion

The ability to efficiently route message and appropriately select the candidate node through intermittently connected networks is critically important in DTNs. Most of the algorithms in hybrid family achieve high delivery ratio but still with relatively high overhead ratio. Besides, the limited network resource degrades the performance due to the contention of the buffer space and bandwidth usage. With a novel multi-forwarding model based on the dynamic message classification and an asymmetric spray scheme, our proposed algorithm outperforms other state of the art algorithms in terms of message delivery ratio, overhead ratio and average latency with lower energy consumption as well.

References

1. Fall, K., Farrell, S.: DTN: an Architectural Retrospective. IEEE Journal on Selected Areas in Commun. 26(5), 828–836 (2008)
2. Jain, S., Fall, K., Patra, R.: Routing in a Delay Tolerant Network. In: SIGCOMM 2004, Portland (September 2004)
3. Daly, E., Haahr, M.: Social Network Analysis for Routing in Disconnected Delay-Tolerant MANETs. In: MOBIHOC, Montréal, Québec, Canada (2007)
4. Musolesi, M., Masclo, C.: CAR: Context Aware Adaptive Routing for Delay Tolerant Mobile Networks. IEEE Transaction on Mobile computing 8(2), 246–260 (2009)
5. Grossglauser, M.: Tse DNC.: Mobility increases the capacity of ad hoc wireless networks. IEEE/ACM Transactions on Networking 10(4), 477–486 (2002)
6. Becker, D.: Epidemic routing for partially connected ad hoc networks. Technique Report, CS-2000-06, Department of Computer Science, Duke University, Durham, NC (2000)
7. Spyropoulos, T., Psounis, K., Raghavendra, C.: Effcient routing in intermittently connected mobile networks: The multiple-copy case. IEEE/ACM Transactions on Networking 16(1), 77–90 (2008)
8. Lindgren, A., Doria, A., Schelén, O.: Probabilistic Routing in Intermittently Connected Networks. In: SIGMOBILE Mobile Computing Communications Review (July 2003)
9. Burgess, J., Gallagher, B., Jensen, D.: MaxProp: Routig for Vehicle-Based Disruption Tolerant Networking. In: IEEE INFOCOM 2006, Barcelona (April 2006)
10. Spyropoulos T., Psounis, K., Raghavendra, C.: Spray and Focus: Effcient mobility Assisted routing for Heterogeneous and Correlated Mobility. In: PerCOM, Newyork (March 2007)
11. `http://www.netlab.tkk.fi/tutkimus/dtn/theone/`