LSSTCS-A SOCIAL-BASED DTN ROUTING IN COOPERATIVE VEHICULAR SENSOR NETWORKS

TONG WANG, YONGZHE ZHOU AND XIBO WANG

College of Information and Communication Engineering, Harbin Engineering University, Harbin, China

YUE CAO*

Department of Computer and Information Sciences, Northumbria University, Newcastle Upon Tyne, NE2 1XE, UK

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As a cooperative information system, vehicles in Vehicular Sensor Networks delivery messages based on collaboration. Due to the high speed of vehicles, the topology of the network is highly dynamic, and the network may be disconnected frequently. So how to transfer large files in such network is worth considering. In case that the encountering nodes which never meet before flood messages blindly to cause tremendous network overhead. We address this challenge by introducing the Encounter Utility Rank Router(EURR) based on social metrics. EURR includes three cases: Utility Replication Strategy, Lifetime Replication Strategy and SocialRank Replication Strategy. The Lifetime Replication is promising complement to Utility Replication. It enhances the delivery ratio by relaying the copy via the remaining lifetime. Considering network overhead, the SocialRank Replication replicates a copy according to the SocialRank when two communicating nodes do not meet before. The routing mechanism explores the utility of history encounter information and social opportunistic forwarding. The results under the scenario show an advantage of the proposed Encounter Utility Rank Router (EURR) over the compared algorithms in terms of delivery ratio, average delivery latency and overhead ratio.

Keywords: Social Network; Vehicular Sensor Networks; Cooperative Information System; Large File Transferring

1. Introduction

Recent years, Vehicular Sensor Networks (VSNs) [1,2], new infrastructure for cooperating vehicular is emerging. They are composed of highly dynamic moving vehicles which are equipped with on-board sensors to relay data messages via wireless communication, and are envisioned to support a variety of urban monitoring and safety applications such as cooperative traffic monitoring, prevention of collisions

*Corresponding author. e-mail: yue.cao@northumbria.ac.uk

and road surface monitoring. VSNs are envisioned to support the variety of urban monitoring and safety applications such as cooperative traffic monitoring, prevention of collisions and road surface monitoring. They are placed in vehicles or along the roads to create an end-to-end reliable network for disseminating sensor data collected from the vehicle environment. Therefore, how to make the models at the node level and multi-nodes at the network level cooperatively and effectively work together to complete a complex task is one of the hot research topics. There are primary two kinds of VSNs routing protocols from the view of their collaboration: cooperation,which means that all nodes work cooperatively according to their own contribution degrees to the objectives, such as cooperative sensing; competition, which means that resources take part in the collaboration according to their competitive strength, such as resources scheduling. In addition, due to the high speeds of vehicles, the topology of the network is highly dynamic, and the network topology may be disconnected frequently. So how to transfer large files in such a network is worth considering.

These network properties associated with Delay/Disruption Tolerant Networks (DTNs) are concerned by the research. In Recent years, Social Networks are widely applied in Delay and Disruption Tolerant Networks (DTNs) [3,4]. DTNs suffer from frequent disruption, sparse network density, and limit capability of devices. Since routing is an inherently cooperative activity [5], system operation will be critically impaired unless the cooperation is somehow incentivized. Routing in DTNs aims to achieve high delivery ratio and low overhead ratio relatively, gets along with delivery latency due to the Store-Carry-Forward (SCF) routing mechanism. SCF concerns that contemporaneous end-to-end paths towards destination are unavailable. As reviewed in [6], although forwarding a message with a single copy [7, 8] makes sure a low redundancy and reduces the cost of network, the routing performance suffers from low delivery ratio and high delay dramatically. On the contrary, generating multiple messages are more effective due to the increasing possibility that one of the copies would be delivered before the given message expiration deadline. Although latter operation increases message delivery ratio, it suffers from replication redundancy inevitably [9] and decreases the routing efficiency.

Considering how to balance the number of forwarding copies, there are two methods to solve this problem. On the one hand, these algorithms replicate messages to any better candidate node based on the utility metric [10–14]. The utility metric can be defined in various way based on the history encounter information. These algorithms do not limit the number of copies that a message can be replicated. On the other hand, these kinds of algorithms limit the number of replicated copies of a message up to L by selecting the candidate node according to utility metric [15–18]. L is evaluated according to the scenario. In comparision, the latter branch is accustomed to scenario where the nodes move fast. The former branch guarantees the delivery ratio, but sacrifices replication redundancy according to the routing mechanism. Despite of existing algorithms' contributions, previous work do not adequately consider balancing the delivery ratio and overhead ratio by limiting the number of copies.

Meanwhile, since mobile device carriers are usually connected with certain social relationships, social network-based routing algorithms have been proposed recently. These nodes are divided into different groups [19–21] through community division. The routing mechanism chooses the nodes with high centrality or similarity. These methods are similar to the utility routing except that they further consider social factors in delivery ability calculation. At present, these general social algorithms are based on graph theory and lack of historical encounter information [22]. We associate a hybrid routing with historical encounter information and social attributes to balance the delivery ratio and overhead.

In this paper, we adopt the replication approach via multiple message copies rather than the forwarding approach via a single message copy. The algorithms which limit the copy of messages are better than the algorithms which do not limit the copy. At the same time, we take the social relationship into consideration to rank the nodes. The key contributions of our study are summarized as follows:

- We put forward three-phases architecture which is different from traditional two-phases algorithms. Because we exploit a new phase named SocialRank Replication to reduce the redundancy in the network. The Utility Replication controls replication redundancy by selecting the candidate node via the utility metric. The Lifetime Replication enhances the delivery ratio by relaying the copy via the lifetime remaining. The SocialRank Replication considers the worst case, the historical encounter information in relation to destination is unavailable due to the message-carrying node and destination node have never met before. Our routing mechanism is that message carrier relays the message according to the rank.
- We propose utility used in Utility Replication based on encounter durations and encounter time interval. The utility with the limitation is to promote message replication when message carrier is moving away from destination. The motivation is to only address the value of history encounter utility metric between currently encountered node and previously encountered node, rather than the comparison between message carrier and currently encounter node.
- In order to select better candidates in the network, we establish a social graph among vehicles when they socially related to each other in SocialRank Replication. Such social relationships are based on friendship, we rank the nodes according to the encounter time interval. In fact, the more frequently two nodes meet, the faster their rank increases. Then send the message replicas based on the rank.

The remainder of this article is structured as follows: Section II introduces a summary of related work. We then propose the Encounter Utility Rank Router in Section III. The section IV describes simulation of proposed EURR algorithm. Its performance is evaluated and compared with other classic routing schemes. At last, conclusion is made in Section V.

2. Related Work

In this section, we introduce two branches of mainstream routing based on utility forwarding and social network.

2.1. *Utility Forwarding Family*

Regarding the algorithms in this family, a message is forwarded using single copy according to the utility metric, where this metric can be defined in various ways to qualify the encountered node.

The Seek-and-Focus [15] adopts the recent encounter time as the utility metric in the Focus phase for utility forwarding. Furthermore, there is a timer in the Focus phase, which shifts the Focus phase into Seek phase to perform a random forwarding approach. [23] introduces a branch of algorithms based on Geographic Utility. MOVE [24] utilizes the moving direction as the utility metric and the message is forwarded to the candidate node which moves towards the destination. Context Aware Routing (CAR) [8] integrates the SCF behavior and traditional end to end approach, uses the Kalman filter to predict encounter. The classic Dijkstras approach can also be utilized. Initially, the link delay has been adopted for the algorithms proposed in [25]. However, such approach is limited by the opportunistic scenario with unpredictable mobility. The algorithms based on congestion control forward messages by considering the available buffer space. The work in [26] adopts a push-pull mechanism to temporarily allocate the storage for the incoming message. Recently, back pressure based algorithm [27] is borrowed into DTNs to relay messages according to the queue differential.

Encounter-Based Routing [28] is a quota-based routing protocol which limits the number of replicas of any message in the system to minimize network resource usage. EBR makes routing decisions based on nodal encounter rates. Showing preference message exchanges to nodes which have high encounter rates. These routing decisions result in higher probability of message delivery. Encounter-based Replication Routing (EBRR) [29] is defined as a utility metric based history encounter information. It is divided into three phases: in Utility Replication Phase, the algorithm controls replication redundancy by selecting the candidate via the utility metric; in Conditional Replication, the algorithm takes the utility and message remaining lifetime into account to reinforce the stability of delivery reliability; in Probabilistic Replication Phase, considering the worst case, the historical encounter information in relation to destination is unavailable due to rare encounter. Encounter-based Spraying Routing (EBSR) [29] extends EBRR by limiting the number of message copies and proposes a spray based routing scheme. Both EBRR and EBSR share the same operation for updating the routing information. But when the message's lifetime is insufficient, the message carrier still forwards the copy based on utility. This kind of routing decision cannot raise the delivery ratio effectively.

2.2. *Social Network Family*

The characteristic of DTNs is robust to the selfish behavior in social networks. SimBet [30] adopts the betweenness and similarity for routing decision. Compared to other centrality calculation methods, betweenness is better to control the spread of the message. The drawback of Simbet is that it just considers the counts of encounters instead of their social relations between neighbors. SimBetAge [31] introduces the aging factor. It redefines the similarity and introduces flow betweenness, directed betweenness and other metrics to deal with the dynamics of social networks and adjust social network metrics. The disadvantage of SimbetAge is that betweeness and similarity do not participate forwarding decisions. It will cause that betweeness has odds to guide the wrong direction.

BUBBLE [20] borrows the concept of distributed community to bubble message up to the target community of destination. [32] introduces four social-aware date diffusion schemes according to the data similarity of the contacts social relationship. But BUBBLE may choose the next hop unreasonably because centrality not reflect the closeness of the relay node and the destination node. CROP [33] combines community structure with a new centrality metric called community relevance. LocalCom [34] is a community-based epidemic forwarding scheme. First, it detects the community structure of the network using the local information of nodes. Then, this information will be transmitted to each community via the gateway.

Above algorithms are based on graph theory, in PeopleRank [35] algorithm, nodes are ranked by using tunable weighted social information. PeopleRank will give higher weight to nodes if they are socially connected to other important nodes of the network. PeopleRank does not take the closeness between relay node and destination node into consideration. Furthermore, RIM [36] evaluates the performance of data forwarding based on the relative importance metric and proposes an online method to compute node's relative importance. However, calculating the rank based on the times of encounter is worse than calculating the rank based on encounter time interval.

3. The Proposed Encounter Utility Rank Routing Protocol

In this section, EURR's routing framework is presented and its work flow is shown in Fig. 1. Firstly, we introduce how to calculate essential information such as encounter time interval utility and SocialRank. Then, EURR considers the following three cases: in Utility Replication phase, messages are efficiently replicated to a better qualified candidate node based on the analyzed utility metric related to destination; if remaining message lifetime is short, EURR will jump into Lifetime Replication phase, messages will be conditionally replicated if the node with a better utility metric has not been met; EURR will jump into SocialRank Replication phase if the information in relation to destination is unavailable in the worst case. Messages are probabilistically replicated based on SocialRank. Next the key technologies of EURR will be presented as follows.

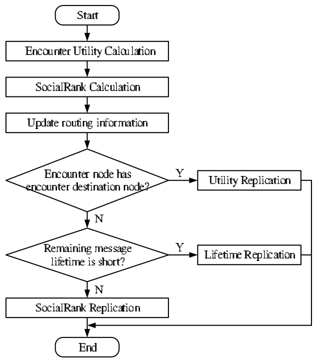


Fig. 1. Overview Flow Chart of EURR

3.1. *Calculation of Utility*

As reviewed in [28], a node with better quality of utility metric implies a higher message delivery potential. Given the encounter factors between nodes N_i and N_j, where $N_i, N_j \in K$, encounter count $C_{i,j}$, encounter duration $D_{i,j}$ and encounter period time $P_{i,j}$ are addressed. The list of commonly used variables are defined in TABLE 1.

Table 1. List of Notations

N_i	Message carrying node with destination information
N_j	Encountered node
N_d	Destination of message
M	A message carried by N_i
T_M^{sta}	Standard message lifetime
T_M^p	The past time since message generation
$D_{j,d}$	Encounter duration between N_j and N_d
$P_{j,d}$	Encounter period time between N_j and N_d
$I_{j,d}$	Encounter time interval between N_j and N_d
$C_{j,d}$	Encounter count between N_j and N_d
$U_{j,d}$	Utility value estimated for N_d, calculated by the historically encounter information which is recorded in N_j
T_M	Threshold value cached in M, for recording $U_{j,d}$
R_{eg}	Rank according to encounter gap utility
m_t	Total number of M replicas which stored at N_i
f	Factor which is defined as the probability
H	Current encounter count
L	Initialized copy ticket of M
K	Total number of nodes in network

We should consider $(P_{i,j} - D_{i,j})$ rather than only consider $P_{i,j}$. $(P_{i,j} - D_{i,j})$ is defined as encounter time interval $I_{i,j}$. For $I_{i,j}$ is influenced by $P_{i,j}$ and $D_{i,j}$ at the same time, $I_{i,j}$ will has a low value when $P_{i,j}$ is low or $D_{i,j}$ is long. It means that N_i and N_j would have short time to encounter each other, while with a long encounter duration for message transmission at previous encounter opportunity. The number of encounters $C_{i,j}$ is decided by the average value of $I_{i,j}$, so different combinations of encounter durations and inter meeting times may result in the same encounter gap. Thus, we define the utility $U_{i,j}$ as:

$$U_{i,j} = \frac{T_{i,j}^{(C_{i,j}=1)} + \sum_{(C_{i,j}=2)}^{H} \left(I_{i,j}^{(C_{i,j})} \right)}{H} \tag{3.1}$$

where H is the value of current encounter count. For example, assuming $P_{i,j}^{(C_{i,j}=1)} = 40$, $D_{i,j}^{(C_{i,j}=1)} = 2$ at the 1^{st} encounter, while $C_{i,j} = 4$ and $T_{i,j}^{(C_{i,j}=2)} = 10$ are recorded for the second encounter, then $U_{i,j}$ is calculated as:

$$U_{i,j} = \frac{40 + (10 - 4)}{2} = 23 \tag{3.2}$$

Note that given the 1st time counter, the encounter duration is 0 before pairwise nodes meet each other. Because the topology based utility metric is unstable, particularly under the high dynamic scenario, this intention estimates the average value of $I_{i,j}$ to adapt to this situation.

3.2. *Update Routing Information*

The method of updating information between any pairwise encounter nodes is as follow: first of all, $P_{i,j}$ is always updated prior to $D_{i,j}$, because only when the link between two nodes is disrupted, the valid encounter duration will be calculated. Next, $P_{i,j}$ is updated with the change of $C_{i,j}$, which implies a new value of $P_{i,j}$ should be calculated for a new encounter. $U_{i,j}$ is simply updated by given $P_{i,j}$ when they encounter each other for the 1st time. Otherwise, it is updated according to (3.1).

Algorithm 3.1 Update History Encounter Information

if A connection between N_i and N_j is established **then**
    both N_i and N_j update the number of encounter $C_{i,j}$
    both N_i and N_j update the encounter period time $P_{i,j}$
    both N_i and N_j update the utility $U_{i,j}$
    for each $N_k \in K$ encountered by N_i in the past **do**
        if $N_k = N_j$ **then**
            skip this N_k
        else if N_k is encountered by N_j in the past **then**
            if $(U_{i,x} > U_{i,j} + U_{j,x})$ **then**
                replace the value $U_{i,k}$ with $(U_{i,j} + U_{j,k})$
            end if
        end if
    end for
else if The connection between N_i and N_j is disconnected **then**
    both N_i and N_j update the encounter duration $D_{i,j}$
end if

3.3. *Calculation of SocialRank*

In copy forwarding phase, traditional algorithms blindly flood messages. In our algorithm, we introduce a method that using a social rank to forward the copy. A social rank R_{eg} is defined as:

$$R_{eg}(N_i) = (1 - f) + f \sum_{N_j \in L(N_i)} \frac{R_{eg}(N_i)}{F(N_j)} \tag{3.3}$$

where N_i, N_j, ..., N_n are the nodes (devices), $L(N_i)$ is the set of neighbors that links to N_i, and f is the factor which is defined as the probability when the social relation between the nodes helps to improve the rank of these nodes. It means that the higher value of f, the more algorithm accounts for the social relation between the nodes. As a result, the factor is useful for controlling the weight that given to the social relations for forwarding decision. Since social graphs are built on different types of information, such mechanisms are very important. We can foresee that a friendship between two individuals defined a stronger social relation than one defined by one or multiple common interests. When using SocialRank for message forwarding, we set the value of damping factor to close to one for strong social relations. This issue is addressed in more details and the impact of the factor on the SocialRank performance is examined in the next section.

3.4. *the Design of Encounter Utility Rank Router*

According to the previous background on utility metric, we introduce EURR in this section. As illustrated in Algorithm 3.2, only if N_i directly encounters N_d, N_i will deliver the message M to the N_d, otherwise N_i will not make any routing decision. If a message copy is already in the buffer, the routing mechanism will ignore the process of this message.

3.4.1. *Utility Replication*

In this routing strategy, if N_j has contained the information about $U_{j,d}$ and $U_{i,d} > U_{j,d}$, N_j will have a higher potential to encounter N_d, then N_i will forward messages to N_j. Furthermore, we define an additional factor (T_M in message M), initialized as:

$$T_M = \begin{cases} U_{i,d} & \text{if } N_i \text{ has encountered destination } N_d \\ +\infty & \text{if } N_i,\ N_d \text{ has never met before} \end{cases} \tag{3.4}$$

At the time of each message generated, T_M will be initialized to an infinite large value if N_i do not meet N_d before, that means N_i has least potential to encounter N_d. Otherwise, T_M is initialized as the value of N_d, considering that N_i has already met N_d since message generation. According to above description, the N_i replicates message copy M to N_j in this case:

$$(T_M > U_{j,d}) \tag{3.5}$$

Algorithm 3.2 Routing Strategy of EBRR

initialize the value of T_M
for each encounter between N_i and N_j **do**
    for each M carried by N_i **do**
        directly deliver M if it is destined to N_j
        update T_M if N_j has a copy of M
        update T_M if $((U_{i,d} < T_M)$ and $(U_{i,d} \neq N/A))$
        if $(U_{j,d} \neq N/A)$ **then**
            if $(T_M > U_{j,d})$ and$(L > 1)$ **then**
                update T_M towards $U_{j,d}$
                replicate $m_t \times \frac{U_{i,d}}{U_{i,d}+U_{j,d}}$ to N_j according to Utility
            else if $((T_M > U_{j,d})$ and $(L = 1))$ **then**
                update T_M towards $U_{j,d}$
                forward M to N_j using single copy
            else if $(T_M > T_M^{sta} - T_M^p)$ and $(L > 1)$ **then**
                if $(\frac{T_M^{sta}-T_M^p}{T_M^{sta}} > \frac{1}{10})$ **then**
                    replicate M to N_j according to Utility
                    keep the rest for M in N_i
                else if $(\frac{T_M^{sta}-T_M^p}{T_M^{sta}} \leq \frac{1}{10})$ **then**
                    replicate M to N_j anyway
                    keep the rest for M in N_i
                end if
            end if
        else if $U_{j,d} = N/A$ and $(L > 1)$ **then**
            if $R_{eg}(j) > R_{eg}(i)$ **then**
                replicate $m_t \times \frac{R_{eg}(N_i)}{R_{eg}(N_i)+R_{eg}(N_j)}$ to N_j based on R_{eg}
                keep the rest for M in N_i
            end if
        end if
    end for
end for

Based on these routing mechanisms, this algorithm is recorded as previously encountered node utility metric and compared with the node upcoming. In view of this, the condition (3.5) focused more on practical indicators, only the nodes between the current node and previously encountered node, rather than comparison between the current node and the message carrier. In order to reduce the redundancy of the network, we spread the copies according to the utility. Defined as:

$$m_t \times \frac{U_{i,d}}{U_{i,d} + U_{j,d}} \tag{3.6}$$

3.4.2. *Lifetime Replication*

We focus on the situation that the remaining lifetime would not be enough. It incurs that message carrier always keeps the message . Furthermore, it results in a longer delay in the delivery, even reduces the probability of deliver due to the short lifetime of the message. To solve these problems, therefore, the condition (3.7), we present before the expiry of the deadline, after the delivery of the message is given by:

$$(U_{i,d} \leq T_M^{sta} - T_M^p) \tag{3.7}$$

where T_M^p is defined as the time that a message is generated, while T_M^{sta} is defined as the initialized message lifetime. Because the message should be delivered to the destination before remaining message lifetime $(T_M^{sta} - T_M^p)$, the intention of using condition $(U_{i,d} \leq T_M^{sta} - T_M^p)$ to make message replication, implies that N_j would encounter other nodes with the condition $(U_{i,d} > U_{j,d})$ in future. According to [28], when $\frac{T_M^{sta} - T_M^p}{T_M^{sta}} \leq \frac{1}{10}$, the message is hard to forward to the destination node before the deadline, we should flood message in a low level in order to raise the delivery ratio. In this situation, N_i forwards a copy to the encounter node N_j anyway.

3.4.3. *SocialRank Replication*

When the value of $U_{j,d}$ is "N/A", that means N_j did not meet N_d in the past. Our algorithm uses SocialRank R_{eg} to forward the message copies instead of blindly flooding messages. The R_{eg} is defined as:

$$R_{eg}(N_i) = \sum_{N_j \in L(N_i)} U_{i,j} \tag{3.8}$$

where N_1, N_2, ..., N_n are the nodes, $L(N_i)$ is the set of neighbors that linked to N_i, $U_{i,j}$ is the Utility between N_i and N_j. Based on (3.8), we find that the lower value of SocialRank means that it is closer to other nodes in network. For example,when message carrier N_i encounters candidate node N_i, the SocialRank $R_{eg}(N_i) \leq R_{eg}(N_j)$ means that N_i has the better quality to destination N_d, for every message M_i, N_i sends

$$m_t \times \frac{R_{eg}(N_i)}{R_{eg}(N_i) + R_{eg}(N_j)} \tag{3.9}$$

replicas of M_i, m_t is the total number of M_i which stored at N_i.

4. Performance Evaluation

We simulate an environment based on the cooperative information system in VSNs.The performance is evaluated using the Opportunistic Network Environment (ONE) [37–39].The ONE is an open source simulation environment that is capable of generating node movement using different movement models. It is suitable to forward messages between nodes with various DTN routing algorithms. The ONE is based on JAVA that can provide the mobility model, routing, and visualization. At the same time, it has a powerful report function to analyze the simulation result.

Fig. 2. Illustration of Scenario

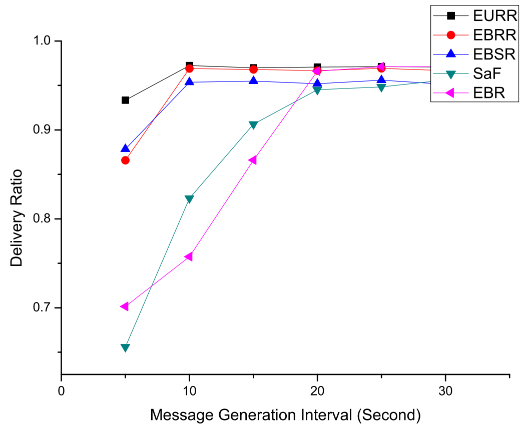
In our simulation, we apply the default Helsinki map with $4500 \times 3400\ m^2$ area as shown Fig. 2 in ONE. Our assumption is that there are light weight vehicles in the network, so we configure 100 nodes with 3-10 m/s. Each node selects the shortest path to an interested point via the Dijkstras shortest path scheme. This scheme depends on its current location and moving speed. Referring to [29,39,40],the communication technique is configured as 4Mbit/t bandwidth and 30m transmission range, which is considered as a low power WiFi technique. The default buffer space is limited to 40MB.

Considering large file transmission like multimedia content, the message size is set with 1MB, 30s generation interval, and 90 minutes lifetime. In order to fully test the delivery reliability, the message generation starts from 0s and ends at 43200s.

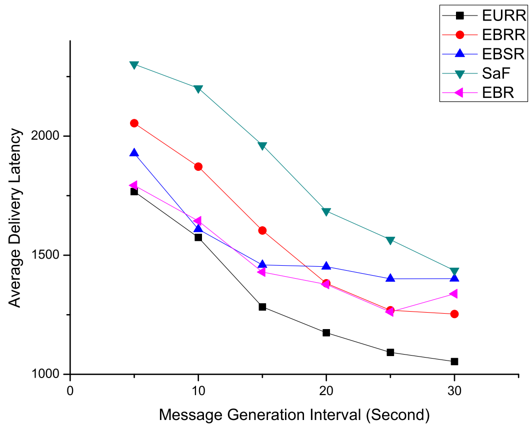
There is a check function before making any routing decision due to the ONE's working principle. If the encountered node is communicating with other nodes, no additional operation about that node will be done.

4.1. *Influence of Message Generation Interval*

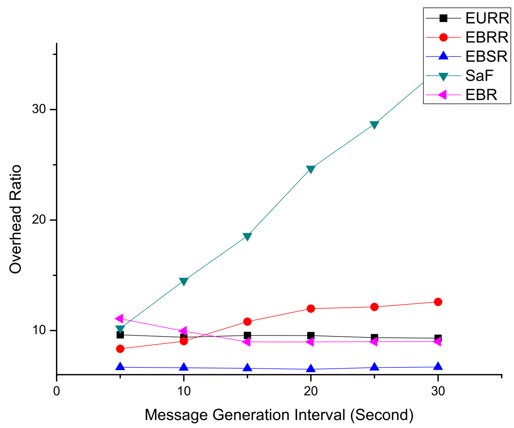
We observe that EURR achieves the highest delivery ratio compared with other algorithms in Fig. 3, thanks to only making a limited number of message copies in the network and spraying the copies according to the rank of encounter time interval. When the message generation interval becomes longer, the replication based routing like EBRR begins to outperform the spray based routing schemes like EB-SR and SaF, because there are more copies in the network. Moreover, EURR is not very sensitive to traffic contention, by achieving the smallest fluctuation regarding



(a) Delivery Ratio



(b) Average Delivery Latency



(c) Overhead Ratio

Fig. 3. Influence of Message Lifetime

average delivery latency. We obverse that EBR, SaF and EBRR have a dramatically increased overhead ratio. To the contrary, EURR maintains a stable performance due to their forwarding mechanism. It implies that proposed routing is advanced for guaranteeing message delivery when bandwidth is limited. Taking into account the fact that the experiment was carried out under adverse conditions, the results were reasonably reliable.

4.2. *Influence of Message Lifetime*

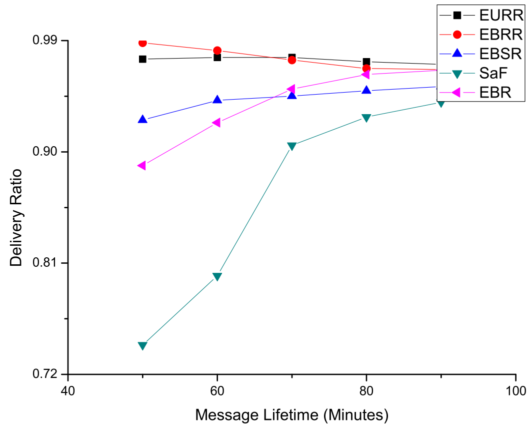
EURR achieves the highest delivery ratio and the lowest average delivery latency, even in a harsh environment which is limited by message lifetime in Figs. 4. Thanks to routing mechanism that based on encountering history information, EBRR is significantly reducing the copies comparing to replication based routing. In particular, the spray based schemes, like EBSR and SaF are with an observable performance improvement. This is because spray based routing schemes rely more on the situation where nodes are sufficiently mobile to encounter each other, as reflected by message lifetime. EBR and EBSR have a low overhead ratio due to controlling the number of copies strictly.

4.3. *Influence of Buffer Space*

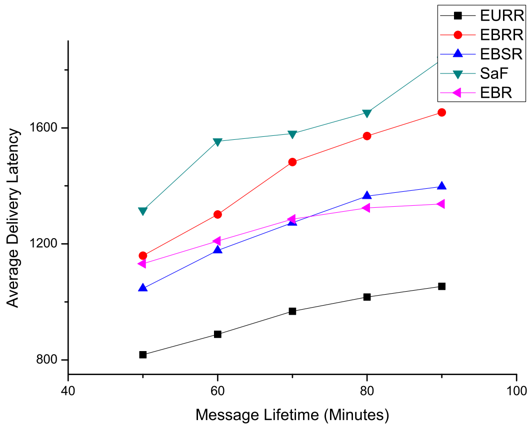
In Fig. 5, EURR is not sensitive to the change of Buffer Space and keeps a stable performance compared with other algorithms. EURR performs a little better than the others in most of the time in the same environment. SaF's delivery ratio is considerably increasing from 8 buffer size to 12 buffer size. Because SaF is sensitive to the change of buffer size. SaF should drop lots of copies when the buffer size is too small according to the forwarding mechanism. When the network is in a harsh environment like the message lifetime maintaining in a low level, most of the algorithms cannot keep a good performance, but EURR maintains a high level, and finishes the work efficiently.

4.4. *Influence of Network Density*

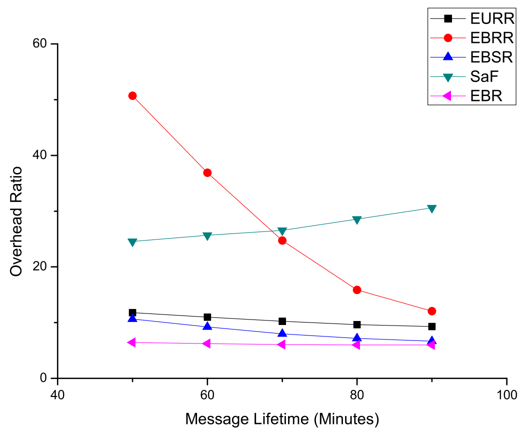
In Figs. 6, we obverse that EURR is efficient in a sparse network density by achieving the highest delivery ratio, and lowest average delivery latency. The reason is that EURR generates additional messages copies in Rank Phase and relays the message to the nodes which have a high possibility of encountering each other in sparse networks. All the algorithms benefit from the increased network density by achieving the decreased average delivery latency. In particular, we observe that SaF does not adequately utilize the increased network density by suffering from the least decrease with respecting to this performance metric. The reason is that the increased network density results in contention for message transmission, which is not properly considered by SaF.



(a) Delivery Ratio

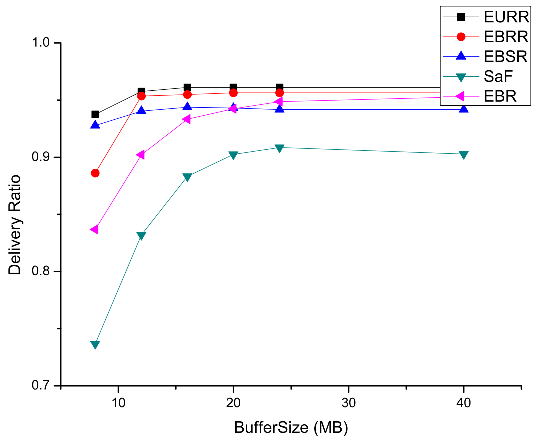


(b) Average Delivery Latency

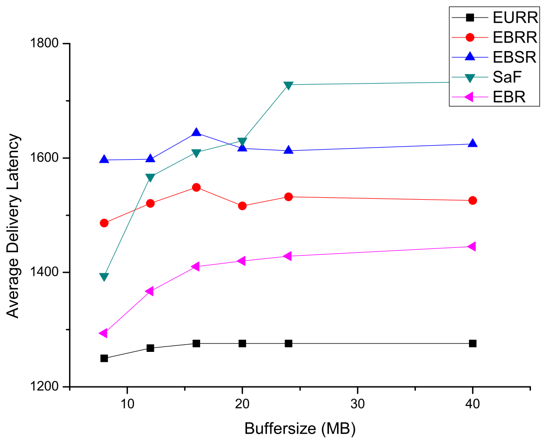


(c) Overhead Ratio

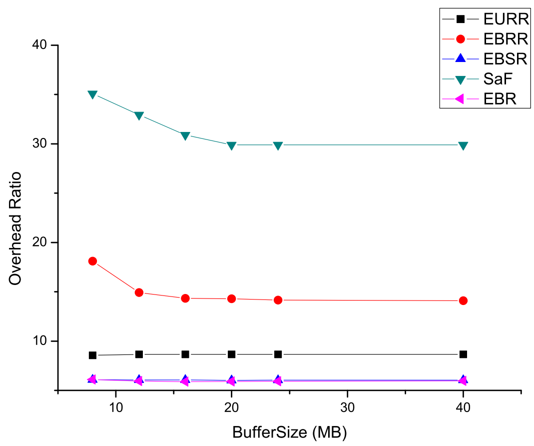
Fig. 4. Influence of Message Lifetime



(a) Delivery Ratio

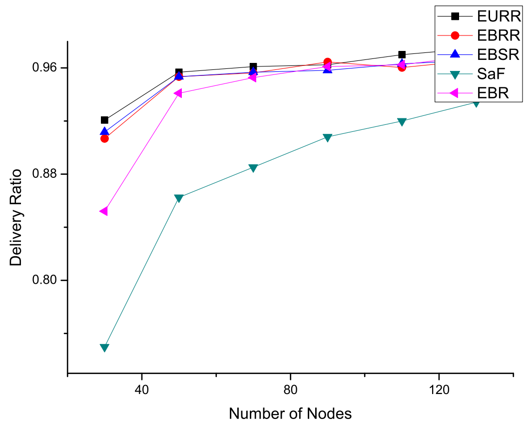


(b) Average Delivery Latency

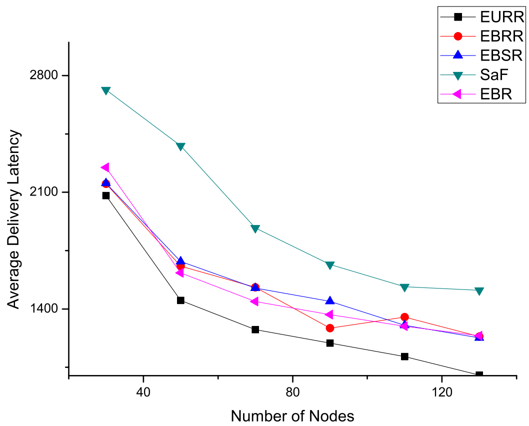


(c) Overhead Ratio

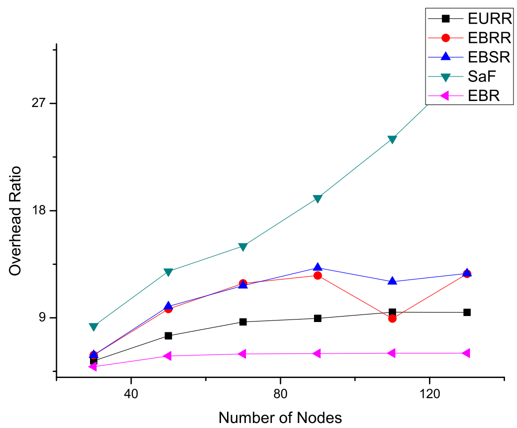
Fig. 5. Influence of Buffer Space



(a) Delivery Ratio



(b) Average Delivery Latency



(c) Overhead Ratio

Fig. 6. Influence of Network Density

5. Conclusion

In this paper, we addressed routing issue by introducing EURR which combined history encounter information and social metric to make the nodes cooperative effectively. We provide a method to balance the delivery ratio and overhead ratio. Results under the scenario show that, it is also essential to consider the design of routing framework to reliably and efficiently deliver messages. Transferring too much routing information according to EURR routing protocol leads to the significant growth of network overhead ratio. In future study, we will solve this issue by optimizing buffer management such as discarding the messages from the buffer space if congestion happens. Meanwhile, we will work on social metric prediction. Our ongoing work will focus on predicting SocialRank according to encounter time interval and depositing the Top-ranked nodes as core nodes dynamically.

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