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A VDTN scheme with enhanced buffer management

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Abstract

Vehicular delay tolerant networks (VDTNs) enable communications in sparse vehicular ad-hoc networks and other challenged environments where traditional networking approaches fail. We propose a VDTN routing scheme that combines the message deliver strategy of PRoPHET protocol, the message copy control strategy of Spray-and-Wait protocol and an enhanced buffer management scheme. In our proposal, the buffer management scheme is designed to improve certain network performance goals, namely, maximizing the average delivery ratio and minimizing the average delivery delay. Furthermore, we use computer simulations to show that the proposed routing scheme achieves better system performance than the existing baseline routing protocols.

Keywords Vehicular delay tolerant networks · Routing protocol · Buffer management

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1 Introduction

Vehicular ad-hoc networks (VANETs) are expected to support a large scale of mobile distributed applications that range from traffic alert dissemination, dynamic route planning and file sharing [1–3]. Wireless communications in VANETs enable vehicle-to-everything (V2X) information exchange. The VANET topology can vary from really dense (e.g., rush hour, traffic jams, and so on) to very sparse (e.g., rural area, late night, and so on). In case of dense network topologies, it is easy to provide an end-to-end multi-hop communication between the source and destination vehicle due to the presence of vehicles on the communication path instead of transmitting data through base stations. In particular, compared to the cellular communication mode, it requires only half of the resources, thus offering better spectral efficiency [4, 5]. On the other hand, in the sparse network topologies, since vehicles movements are unpredictable and vehicles could disconnect or reconnect at anytime, it is difficult to find a stable connection between two nodes. Even some of the existing ad hoc routing protocols can still be applied to VANETs, simulation results have showed that they suffer from poor performances because of the fast movement of vehicles and limited chances for information exchange [4, 6–8]. The communications between vehicles in sparse vehicular network case can be achieved by using the store-carry-and-forward (SCAF) communication mechanism that is the basis of Delay Tolerant Network (DTN) [9].

DTN aims to provide communication capabilities for a wide range of challenged environments, where difficulties exist in establishing end-to-end paths. Recent studies [10, 11] advocate the DTN architecture [12] to support message distributions in highly dynamic networks. Vehicular delay-tolerant networks (VDTNs) create a communication infrastructure composed of vehicular nodes and other nodes, offering a low cost connectivity solution in challenging scenarios where a telecommunication infrastructure is unreliable or not available due to disconnected areas, natural disaster or emergency situations [13]. Many VDTN routing algorithms make forwarding decisions by building and updating routing tables whenever mobility occurs. We believe this approach is necessary since mobility is often unpredictable, and topology structure is highly dynamic.

Many routing protocols have been proposed for VDTNs with an attempt to achieve high delivery ratio and low delay. The simplest protocol is Epidemic routing [14] that replicates messages to all encountered peers that still do not have them. As Epidemic routing incurs a high replication overhead, Spray-and-Wait protocol [15] sets a strict upper bound on the number of copies per message allowed in the network. Another well-known routing protocol is PRoPHET (Probabilistic Routing Protocol using History of Encounters and Transitivity) protocol [16]. It uses the past information of nodes, and the history of the encounters to predict the future encounters and thus select the intermediate nodes. Ample efforts have been made in applying PRoPHET Protocol for multicasting in DTN but they all lack in addressing the issue of buffer management which directly degrades the performance of the protocol. PRoPHET algorithm is a routing algorithm based on probability strategy. This routing algorithm significantly reduces the blindness in forwarding process and improves the success rate of message delivery compared with Epidemic routing. However, with the expansion of network scale, a large number of copies are produced, which could affect the network performance. Moreover, PRoPHET does not optimize the message transmission policy and discard strategy.

Existing studies in the era of VDTN routing protocols can be classified into three main categories. The first category is the study regarding general DTN routing protocols that mainly focus on controlling the data replication procedure based on encounter probability and replication overhead [14–21]. The second category discusses specific DTN protocols under the assumption that certain kind of social contact information is available [22–27]. The third category studies buffer management policies in order to improve the packet delivery ratio especially in the case of limited buffer space or high traffic rate [28–34]. While the buffer management policies could affect the performance of the routing performance, the integration of routing algorithm and buffer management policy is not seriously discussed in the literature.

In this paper, we design a VDTN scheme that efficiently integrates a general routing algorithm with a smart buffer management policy. The major contributions of our work are as follows.

- First, we propose a general routing protocol without assuming the availability of specific social information. The routing algorithm combines the message deliver strategy of PRoPHET with the copy control strategy of binary spray-and-wait protocol to limit the redundant duplication of messages.
- We propose a specific buffer management policy to improve the congestion control strategy of the routing algorithm. The delivery probability and message properties are used to construct a congestion control metric (CCM). Messages with higher CCM have higher priorities to be forwarded in order to improve the buffer utilization. Messages with the minimum CCM are discarded to reduce the impact of random dropping on routing efficiency.
- We conduct exhaustive simulations to evaluate the proposed scheme and show the advantage over other baseline approaches.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of the related studies. Section 3 and Sect. 4 describe the proposed routing algorithm and buffer management policy, respectively. Section 5 provides a comparative analysis of proposed VDTN scheme with some existing baselines, while Sect. 6 concludes this paper.

2 Related work

2.1 General routing protocol

Existing general routing protocols can be divided into three categories, namely, multi-copy-based, single-copy-based, and erasure coding-based. In the first category [14–16], the system keeps more than one copy of the same message, which can be forwarded independently to improve robustness and delivery ratio. The main characteristic that these protocols have in common is the use of a multiple-copy routing strategy that replicates bundles at contact opportunities. Since too many copies may lead to congestion and large overheads, most studies focus on the controlling policy of message replication. In single-copy-based routing protocols [17, 18], only one copy of each message can exist in the network. In the third category [19–21], numerous relays are allowed while a constant overhead is maintained, which results in fewer cases of long delays. However, coding-based approaches are difficult to implement, where the purpose of this paper is to design a general VDTN scheme that is easy to implement.

Epidemic is a flooding-based routing protocol. Nodes continuously replicate and send messages to newly discovered nodes that do not already have a copy of the message. In the simplest case, Epidemic routing is flooding, but more elaborated techniques can be used to limit the number of message transfers. Spray-and-Wait achieves resource efficiency by setting a strict upper bound on the number of copies per message allowed in the network. The protocol is composed of two phases: the spray phase and the wait phase. Spray phase is terminated when the number of replication reaches the upper limit. When a relay node receives the replica, it enters the wait phase, where the relay simply holds the particular message until the destination is encountered directly. It is possible to suppress the communication cost compared with epidemic conventional method. In PRoPHET protocol, the encounter probability is determined from the frequency with which each node makes contact with the target node. By communicating only to nodes with higher encounter probabilities to improve the probability that message will be delivered, and reduce the number of communications. The bandwidth consumption is larger than Spray-and-Wait protocol because it does not control the number of message replications.

As long as enough resources are available in the entire network, the existing protocols can guarantee that messages will eventually arrive at their destinations along the shortest path. Therefore, under ideal conditions, the existing protocols provide a lower bound for delay and an upper bound for delivery probability. However, in a realistic scenario, the network and node resources are often restricted. The existing protocols waste resources by propagating copies of messages that have already been delivered or choosing immediate nodes that will never reach the destination.

2.2 Specific routing protocols

There have been some protocols utilizing the social relationship between nodes to improve the routing performance. In a social-aware network, while nodes are interacted in a diverse manner, certain nodes encounter each other more usually. User's social affiliations and attitudes are generally with long-term properties. Compared with the mobility of nodes, they are less volatile. By utilizing these features, social-based routing protocols use various social characteristics to improve routing performance in DTN environments [22–24].

SCORP (Social-aware Content-based Opportunistic Routing Protocol) [25] is a social-based routing protocol which focuses on message content rather than communication hosts. In addition, nodes' social interactions and structures (e.g. communities) are also under consideration. Social levels of interaction promote the routing performance in opportunistic environments. Content knowledge may be content type, interested parties etc. SCORP uses the combined form of social adjacency and content knowledge in challenging environments in order to take forwarding decisions. When source node is encountered with another node, message will be forwarded from source node if that node has the same content interest of message carried by the source or, that node has strong relationship to the source node. The dLife [26] protocol is another social-aware routing approach which considers the dynamism of users' behaviors based on their daily life, taking advantage of time-evolving social structures. In the dLife, source node delivers a copy of message toward encountered node since it has greater relation with destination than source. The reason behind this is in future there is a good probability to face the destination. When its relationship with destination is not known, then source node forwards the message in accordance with the node's importance. Therefore, nodes having higher importance will get the message from source. Bubble Rap [27] combines node centrality with the idea of community structure to perform forwarding. Communities are formed considering the number of contacts between nodes and their durations, and centrality is seen from a local (i.e., inside communities) and global (i.e., whole network) perspective. Messages are replicated based on the global centrality metric until it reaches the community of the destination (i.e., a node belonging to the same community). The forwarding is done by using the local centrality metric, aiming to reach the destination inside the community.

We can see that the design of social-based DTN routing is more complicated than other approaches. It has to use social concepts from social networks and consider a realistic DTN environment. Although these existing protocols make use of the distributed computation to ensure message diffusion, it requires the knowledge about the social group of destination, which is difficult to achieve. Furthermore, the temporal challenges in acquiring recent social network topology is not discussed.

2.3 Buffer management policy

DTN systems are often composed of resource-constrained wireless or mobile devices. Since the buffer space and inter-node wireless resources in a system are always limited, it is important to enforce buffer management and scheduling policies to maintain message delivery in DTNs. The existing studies cover heuristic-based [28–30] and optimal-based policies [31–33]. The heuristic-based policies employ different states of a message to estimate the probability that a message can be delivered to its destination. For example, hop counts of a message [28], the number of message copies, remaining time-to-live (TTL), elapsed time [29], delivery speed of messages [30], degree of message redundancy [31], and the duration that a message has kept in a node [32] are regarded to name a few. On the other hand, optimal-based policies commonly formulate the message scheduling and dropping task as a message replica allocation problem with respect to delivery ratio or delay. The results of problem solving are transferred into utility functions for scheduling messages in buffer space. RAPID [33] is a typical optimal-based policy. The study [34] argues that RAPID is suboptimal, and then proposes a global knowledge-based scheduling drop policy (GBSD). While there are some buffer management policies, an efficient integration of DTN routing algorithm with buffer management policy is an under-explored research problem.

3 Proposed VDTN scheme and its routing strategy

3.1 Overview of the proposed VDTN scheme

The proposed scheme includes two main components, namely, a routing protocol and a buffer management policy. The routing protocol achieves a good packet forwarding performance by combining the message deliver strategy of PRoPHET with the copy control strategy of binary Spray-and-Wait protocol. The buffer management policy considers several attributes of nodes and messages to construct the congestion control metric to administrate congestion issues.

3.2 Routing algorithm

In order to enhance the data delivery ratio in the VDTN environment where the node movement is difficult to predict, this paper proposes a new general routing algorithm. After a full consideration of node behavioral characteristics, we propose a protocol that controls message copies in message transfer process and distributes message copies according to binary transfer algorithm. The difference against existing protocol is as follows. In the spray phase, the proposed algorithm chooses the node with higher encounter probability to relay message copies. In the wait phase, the algorithm takes into account node historical information, and relays message copies based on encounter probability. The algorithm improves the message delivery probability while reducing the packet forwarding overhead.

Figure 1 shows the routing algorithm conducted at node *A*. In the first step, source node *A* replicates message *M* to *L* copies. The second step executed on *A* checks whether node *B* is the final destination for any of the bundles stored in node *A*'s buffer or not. If it happens, these bundles are scheduled for being transmitted first to *B*, followed by the remaining bundles sent in an order determined by the execution of the next steps. As expected, the bundles that targeted for *B* are removed from *A*'s buffer and added to *A*'s list of delivered bundles. The third step involves the determination of send the message or not. If the encounter probability to the destination node of node *B* is greater than node *A*, go to the next step. The final step is to ensure that there is more than 1 copy in node *A* so it could send half of the copies to node *B* which has higher encounter probability. These steps repeat until the message sent to the destination node.

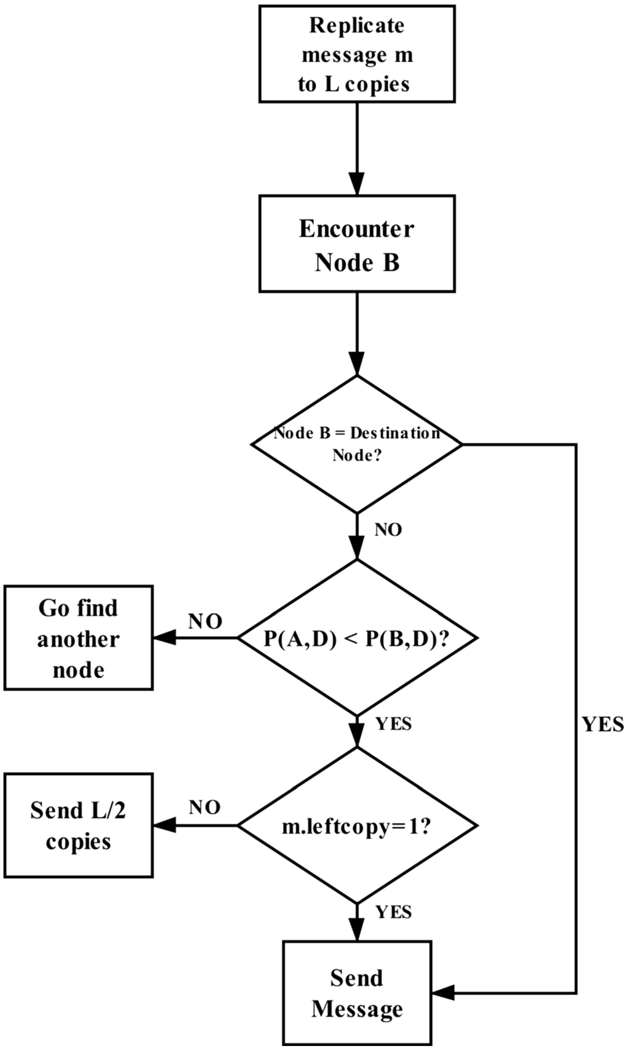

Fig. 1 Flowchart of the proposed routing algorithm

The message sending process is shown in Fig. 2. In section a, node *S* is the source node and has message *m*. In section b, within the communication range of node *S*, there are two nodes *A* and *E*. At the beginning of message transfer stage, node *S* replicates message *m* to *X* copies. Then, the encounter probability with the destination node is compared between node *A* and *E*. If node *A*'s encounter probability is higher than node *E*, Node *S* only considers exchanging data with node *A*. Before sending a message, Node *S* updates the encounter probability of each node where the update method is the same as PRoPHET protocol. When node *A*'s encounter probability to the destination node is higher than node *E*, node *S* gives priority to communication with node *A*. When node *S* decides to sending a message, *X*/2 copies will be sent to node *A* according to the binary transfer algorithm, while node *S* has the remaining *X*/2 copies. In section c, node *S* encounters node *B*, and node *B*'s encounter probability is higher than node *S*. Then, node *S* sends *X*/4 copies to node *B*. In section d, node *C* appears in the communication range of node *A*. Node *A* sends *X*/4 copies to node *C* because node *C* has a higher encounter probability with the destination node. Finally, node *C* sends the copy to the destination node to finish the message transfer process.

4 Proposed buffer management policy

We propose an improved routing protocol based on PRoPHET. Since the network resources such as node buffer size and network bandwidth are always restricted, the buffer overflow problem is easy to occur. Therefore, conducting an efficient buffer management at each forwarder node is necessary in order to improve the packet delivery probability.

By studying the existing buffer management policies, we can find that most of current studies only consider the unilateral attributes of nodes or messages but do not address them as a whole part, therefore blindness exists. We propose a buffer management policy based on the congestion control metric. The metric takes into account several attributes of nodes and messages, including the remaining lifetime of messages, delivery probability, and buffer overhead ratio. When congestion happens, the proposed approach compares the congestion control metric of messages in the buffer and selects the minimum value to discard, which can reduce the packet loss and improve the network performance.

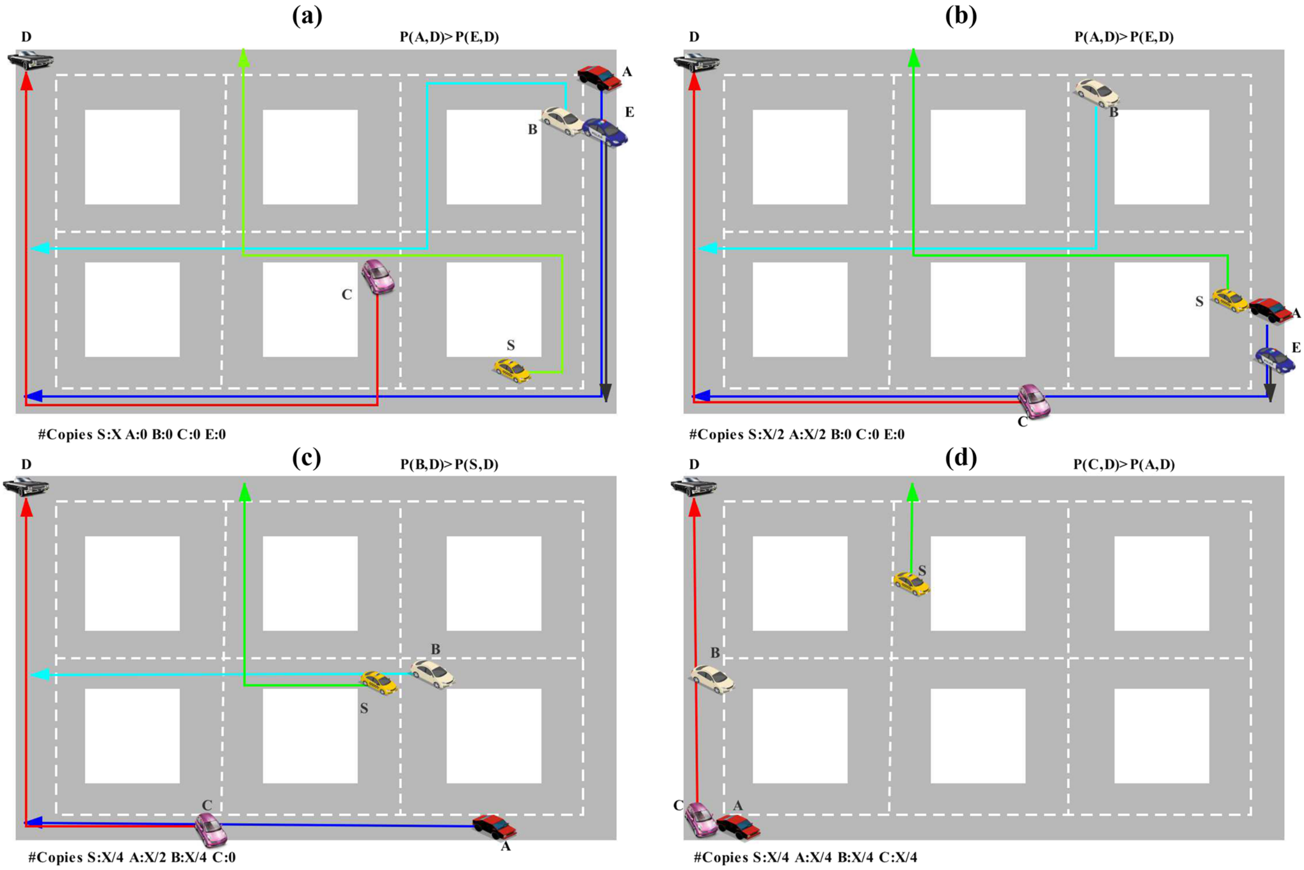

Fig. 2 An example of routing procedure

4.1 Buffer overhead ratio

We use buffer overhead ratio to describe the cache usage of a message replica in a node. In the operations described by the equation that follows, message replica's size in node i is $S_i(m)$, the remaining buffer size of node i is $BS(i)$. Using the ratio of message size and the remaining buffer space represents the buffer overhead ratio $BO_i(m)$.

$$BO_i(m) = \frac{S_i(m)}{BS(i)}. \tag{1}$$

From the Eq. (1), we can know that since the buffer size is constant, if the message size is larger, the influence to other messages in the buffer is greater. Thus the buffer overhead ratio is a negative factor in the buffer management.

4.2 Time measurement factor

Since DTN uses the store-carry-forward method to transport messages, the message TTL is an important element that affects the buffer management. A message occupies the cache for a long time, which will seriously affect the utilization of the cache since it is possible that the message has already been delivered to the destination node. On the premise that there is no feedback mechanism in DTN, if the message is redundant information, then deleting the message replica with the earliest reception time of the node is beneficial to the whole network. Therefore, this part combines the message TTL with the receive time to the buffer and uses their ratio to describe the effect of the time factor on the message. In Eq. (2), $TREC(m)$ is the live time of message m in node i, $TTL(m)$ is the remaining TTL of message m and $TM_i(m)$ is the time measurement factor of message m in node i.

$$TM_i(m) = 1 - e^{\frac{-TTL(m)}{TREC(m)}}. \tag{2}$$

$TM_i(m)$ is a monotonically increasing function less than 1 and has a positive effect to the evaluation of message preservation value.

4.3 Estimation of delivery probability

Due to the discontinuous characteristics of DTN and the fast change of topologies, nodes are required to use the known information to estimate the whole network situation. In this part we use the message hop count and the delivery probability to estimate the delivery probability. Since the proposed protocol is based on the delivery probability concept and uses binary distribution algorithm to send message replicas, the number of relay nodes $RN(m)$ can be estimated by Eq. (3).

$$RN(m) = min\left\{2^{hop_i(m)}, CN(m)\right\}. \tag{3}$$

In Eq. (3), $hop_i(m)$ is the hop count when node i receives message m, and $CN(m)$ is the total number of message copies. We use the ratio of the number of relay nodes and the number of nodes in the network to represent the rate of message m stored in a node i, and then use the product of the ratio and the delivery probability to estimate the delivery probability that message m can be transferred to the destination node.

$$DS_i(m) = \frac{RN(m)}{N} \times P(i, D). \tag{4}$$

In Eq. (4), $DS_i(m)$ is the estimation of delivery probability and N is the number of nodes in the network. $P(i, D)$ shows the probability of one replica of message m transferred from node i to the destination node.

4.4 Congestion control metric

In a node's cache, if the message size is bigger, the fewer messages can be stored in the cache; if the message TTL is larger, the fewer times the nodes can receive the new message and the lower active level the nodes are. In summary, there are many factors can affect whether the message can be successfully delivered to destination node. Therefore, in this part, we comprehensively considered these influencing factors and evaluate the preservation value of the messages in many aspects. In the message dropping policy, the estimation of delivery probability and the time measurement factor are positive factors, and the buffer overhead ratio is a negative factor. The joint consideration of these three parameters is the congestion control metric as follows.

$$CCM_i(m) = \alpha * DS_i(m) + (1 - \alpha) \times \frac{TM_i(m)}{BO_i(m)}. \tag{5}$$

In Eq. (5), the $CCM_i(m)$ shows a overall rating of each message in the buffer. The smaller the $CCM_i(m)$ value is, the lower the priority of the message, which means that the message is more likely to be dropped when a congestion happens. α is the smoothing factor between 0.5 and 1. The large the value of α is, the greater the affect that $DS_i(m)$ has.

4.5 Proposed buffer management algorithm

The buffer management algorithm is shown in Algorithm 1. First, the node checks whether the buffer has enough space when receiving a new message. If the buffer has no enough space for the incoming message which means congestion happens, the algorithm calculates CCM value for each message in the buffer and finds the message has the lowest *CCM* value. Finally, the algorithm drops the message that has the lowest *CCM* value in order to store the incoming message.

Algorithm 1 Buffer management algorithm

```
Message queue $M_1$,$M_2$,...,$M_i$,...,$M_m$
Node $N$
Receive message $M_R$ from other node.
while FreeBufferSize of $N$ <$M_R$
  $MIN = CCM(M_1)$ do
    for Each message $M_i$ do
      Figure out the value of $CCM(M_i)$.
      if $CCM(M_i)$ <$MIN$ then
        $MIN = CCM(M_i)$.
        $M_{min} = M_i$.
      end if
    end for
    Node $N$ drops $M_{min}$.
end while
```

5 Simulation results

5.1 Simulation setup

We conducted computer simulations to evaluate the performance of the proposed scheme. The Opportunistic Network Environment (ONE) simulator was used as the simulation tool [35]. Parameters for simulation setup and routing algorithms are shown in Table 1 and II, respectively. In the simulation, the city map of Helsinki was used, and the simulation time was 43,200 s. The number of nodes was varying from 35 to 95, and all the nodes were cars with moving speed of 10–50 km/h. The node buffer size was changed between 1 and 10 MB. Message generation time was changed between 10 and 100 s. Message living time was changed between 60 and 300 min. The wireless link data rate was 7.5 Mbps and the communication distance was 50 m. The size of the message was an arbitrary value in the region of [500k, 1m]. We evaluated the proposed scheme by changing the buffer size of each node and the number of nodes. The proposed protocol was compared with “PRoPHET” [16], “S&W” (Spray-and-Wait protocol) [15], “Bubble Rap” [27], and “Proposed w/o BMP” (the proposed scheme without buffer management policy). Simulation parameters are shown in Tables 1 and 2.

Table 1 Parameters for simulation setup

Parameters	Values
Simulation time	43200 s
Number of nodes	35,50,65,80,95
Interface	Wi-Fi interface
Interface type	Simple broadcast interface
Transmit speed	7.5 Mbps
Transmit range	50 m
Buffer size	1,3,5,7,10
Message interval	10,30,50,70,100
Message TTL	60,120,180,240,300
Mobility	Random way point
Movement model	Shortest path map based
Message size	500 KB–1 MB
Simulation area size	4500 m × 3400 m

5.2 Results and analysis

We used three performance metrics, specifically, message delivery ratio (i.e., the successfully delivered messages over the total generated messages), the average message end-to-end delay, and the overhead ratio which is the ratio of “number of extra relays made” to “number of direct relays made to destinations”. We have carried out our simulation under different scenarios to study the impact of different network parameters on the network performance.

Figure 3 clarifies that the message delivery probability of all the protocols increases as the buffer size increases. Among them, the message delivery ratio of the proposed scheme is the highest. These results indicate that proposed scheme can deliver the vast majority of the packets to the final destination. This is because the proposed scheme avoids the blindness of the “S&W” protocol, which reduces the amount of data stored in the buffer. “PRoPHET” protocol has the lowest message delivery ratio due to the inefficient flooding scheme. Since the “PRoPHET” protocol does not consider the number of copies, the message delivery ratio is unsatisfactory. By including a limitation on the number of copies in the “PRoPHET” protocol, the proposed scheme shows a significant advantage over other protocols.

Table 2 Parameters for routing algorithms

Routing algorithm	Parameters	Values
PRoPHET	Seconds in time unit	30
Spray-and-Wait	No. of copies (L)	10
Proposed	Seconds in time unit	30
Proposed	No. of copies (L)	10
Bubble rap	k-clique	3

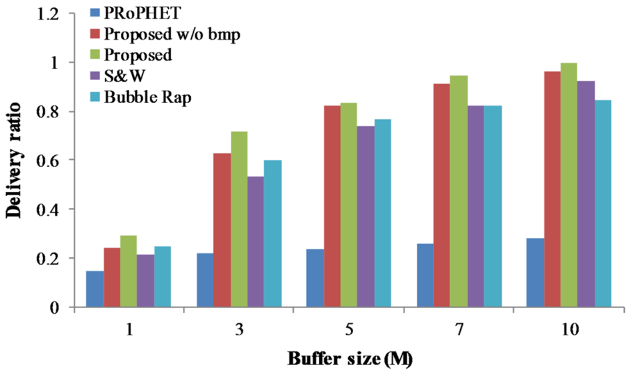

Fig. 3 Delivery probability for various buffer sizes

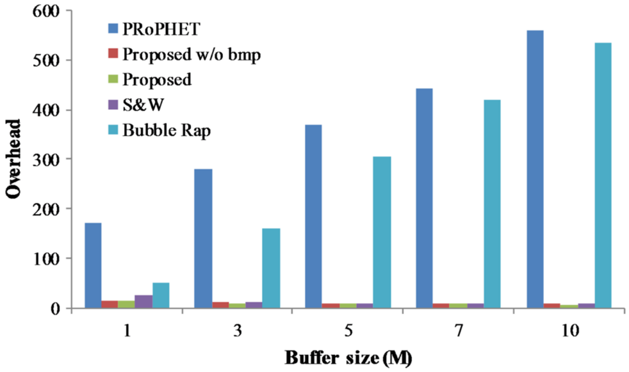

Fig. 4 Overhead ratio for various buffer sizes

Figure 4 shows a change in the overhead ratio of all the routing protocols, which is measured by the number of packet transfers needed for each packet delivery to the destination. For the "PRoPHET" protocol, the overhead increases as the buffer size increases. As the buffer size increases, the number of messages that can be stored before meeting the destination increases, and the redundancy of data is considered to be the cause of the overhead. Since the proposed scheme and the Spray-and-Wait protocol control the copy of the messages from the beginning, the overhead is suppressed.

Figure 5 depicts the average delay. The average delay becomes higher as the buffer size increases. Without using any smart buffer management policy, the "Bubble Rap" protocol shows the highest average latency since there are too much redundant messages in the buffer. In the proposed scheme, when a congestion happens in the buffer, messages will be dropped considering the delivery probability, the message lifetime and buffer space. Therefore, we are able to observe that the proposed buffer management shows a low average latency in all cases.

Figure 6 clarifies that the message delivery probability of all the protocols increases as the message interval increases. Among them, the message delivery probability of the proposed scheme is the highest. This is because the proposed scheme avoids the blindness of the "S&W" protocol and controls the use of buffers. For the "PRoPHET" protocol, since there is no consideration on the copy of messages, the message delivery is also affected.

Figure 7 shows the comparison of the overhead ratio. The overhead ratio of "PRoPHET" protocol and "Bubble Rap" protocol increases as the message interval increases while the overhead ratio decreases for the proposed scheme and Spray-and-Wait protocol. As the message interval increases, the number of messages created in a certain simulation time reduces, resulting in a low probability of packet losses. The redundancy of data is considered to be the cause of the overhead ratio becoming larger. On the other hand, the proposed scheme and the Spray-and-Wait protocol control the copy of the message from the beginning, so the overhead ratio is reduced.

Figure 8 shows the comparison of the average delay time. For all protocols, the average delay time becomes higher as the message interval increases. "Bubble Rap" protocol does not capture such dynamism which leads it to create replicas that take more time to reach the destination due to the weaker social ties of the carrier with the destination. Since the average delay time of the proposed scheme is lower than the "PRoPHET" protocol, the performance is improved.

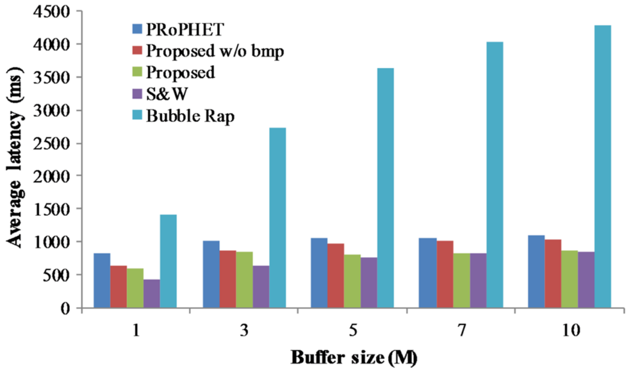

Fig. 5 Average latency for various buffer sizes

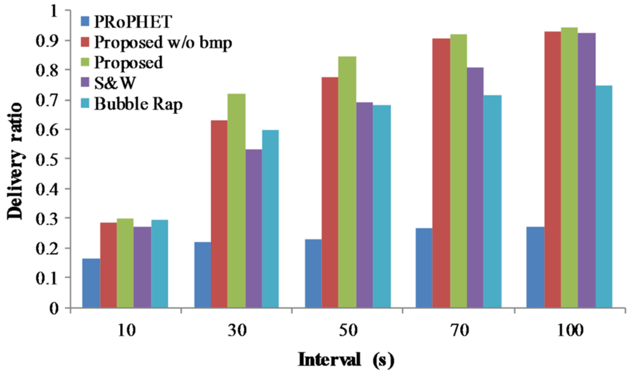

Fig. 6 Delivery ratio for various message intervals

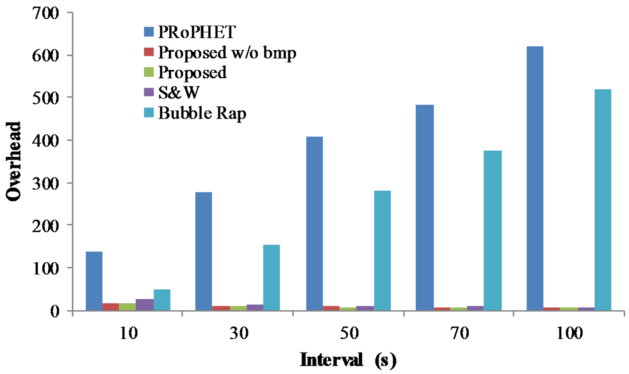

Fig. 7 Overhead ratio for various message intervals

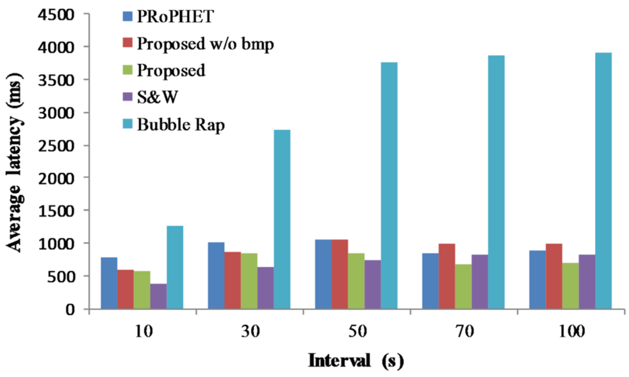

Fig. 8 Average latency for various message intervals

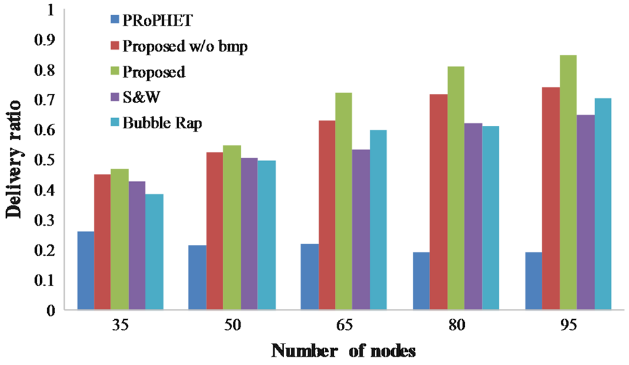

Fig. 9 Delivery ratio for various numbers of nodes

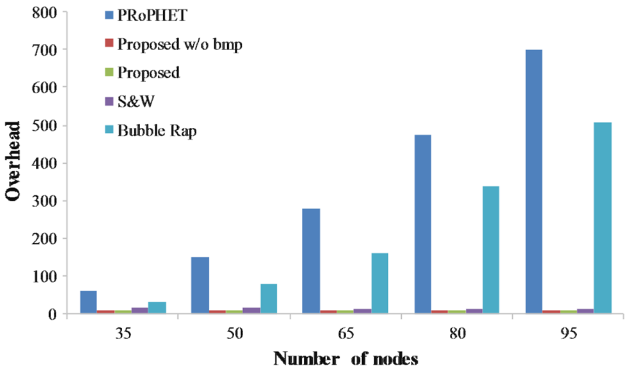

Fig. 10 Overhead ratio for various numbers of nodes

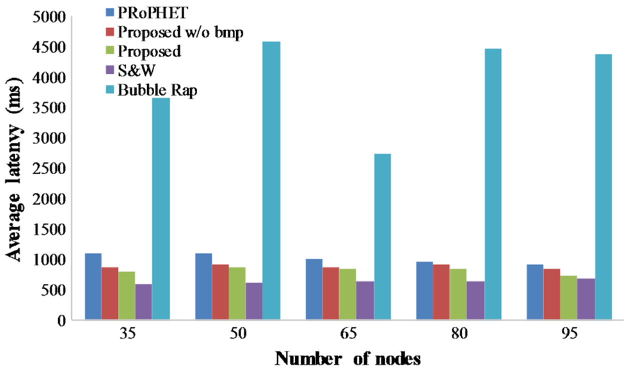

Fig. 11 Average latency for various numbers of nodes

Figure 9 clarifies that the message delivery probability of all protocols increases as the number of nodes increases. Since the proposed scheme and the “S&W” protocol can control the number of copies of messages, when the number of nodes is increased, the opportunities to communicate with other nodes are increased. The overhead and the average delay of the proposed scheme are not sensitive to the node density due to the efficient packet forwarding policy that combines “PRoPHET” and “S&W”. The “PRoPHET” protocol does not control the number of copies of the message, and therefore the message overhead is high, resulting in a decrease of packet delivery ratio with the increase of node density. The proposed scheme is able to outperform other algorithms in any network conditions. Figure 10 demonstrates the transmission overhead of the delivered messages for various node densities. The message overhead of “Bubble Rap” is high due to the fact that a packet requires a high number of hops before delivered.

As we can see the delay of our algorithm is lower than other algorithms, which indicates that the CCM value is effective in Fig. 11. The average latency of proposed scheme is lower than other existing protocols. The fact that proposed scheme outperforms other routing protocols shows that the scheme makes wise decisions on what bundles to forward and how to use the limited resources.

The delivery ratio, overhead ratio, and average latency for various message TTL values are shown in Figs. 12, 13, and 14, respectively. Because of limited resources and short life span of a packet in VDTN, investigating the routing performance for different TTL values is very important for overall network performance. “PRoPHET” relies on encounter history and transient delivery prediction to choose relays. This can efficiently identify the routing paths to the destinations, but the dynamic environment could result fluctuations of predicted probabilities. This results in more redundant nodes being chosen as relays,

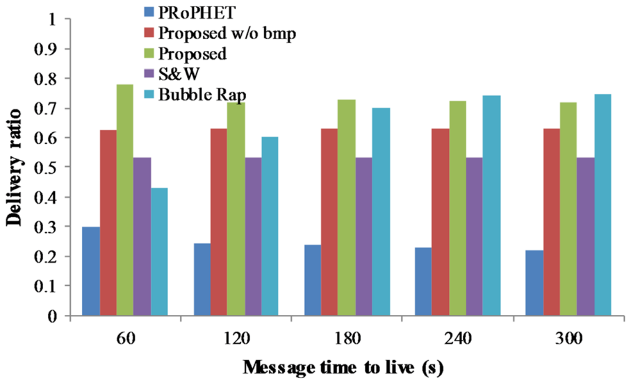

Fig. 12 Delivery ratio for various message TTL values

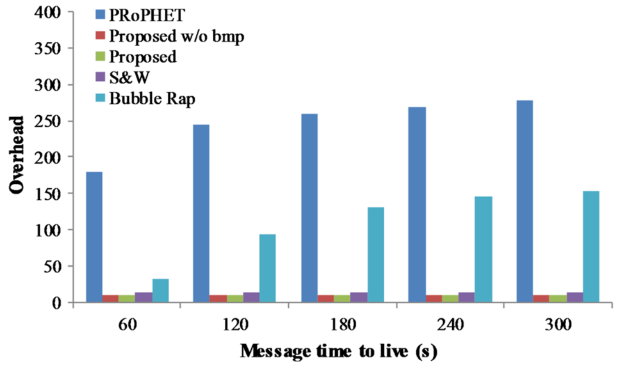

Fig. 13 Overhead ratio for various message TTL values

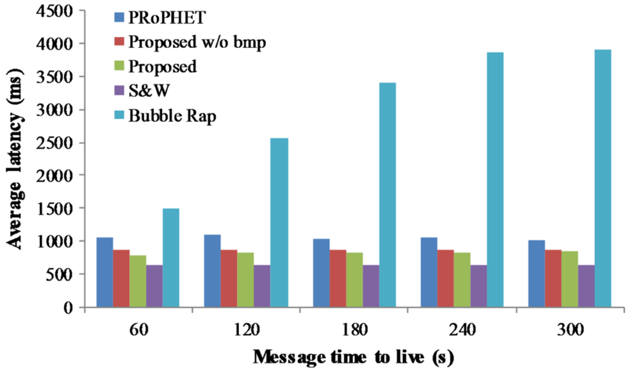

Fig. 14 Average latency for various message TTL values

which can be reflected from the delivery overhead. Since the proposed scheme and "S&W" protocol can control the number of copies of messages, when the number of nodes is increased, and the opportunities to communicate with other nodes are increased. At the same time, the overhead ratio and the average delay time are not affected. On the other hand, since the "PRoPHET" protocol cannot limit the number of copies of the message, the message delivery ratio shows a slight decrease. The overhead of "Bubble Rap" increases with TTL values. We observe that the TTL value has a very little impact on social-oblivious "S&W" and the proposed scheme, while having a significant impact on the social-aware "Bubble Rap" protocol. This performance study inspires us to select the message TTL value that allows the protocols to deliver the most messages with shorter latency and lower cost.

6 Conclusions

We proposed a VDTN scheme that includes both routing protocol and buffer management policy. The proposed scheme takes into account the encounter probability between nodes and the number of copies of the message in the forwarding decision. The buffer management policy combines the delivery successful estimation, time measurement and buffer overhead ratio to calculate the congestion control metric value. Based on the value, the proposed scheme efficiently controls the message drop policy to reduce the impact of message drop on the delivery ratio. Simulation results show that the proposed scheme performs better than existing baseline approaches by providing a higher message delivery ratio and lower overhead.

Our work has some possible future improvements as follows. The existing protocols do not consider the feedback from the destination node about the message reception status. If we could exchange the message reception status information among forwarding nodes, a more efficient buffer management and packet forwarding would be achieved. Most of the existing protocols only consider unicast communications in DTN, however in a realistic communication environment, the network nodes always have to send information to a specific group of nodes due to the node sociality. Therefore, the studies on multicast and anycast communications could be beneficial to enhance communication capability and improve the wireless resource utilization efficiency in DTN.

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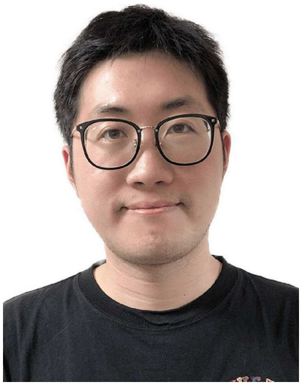

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