Wireless Pers Commun (2017) 96:1803–1817
DOI 10.1007/s11277-017-4269-1

Adaptive Forwarding Scheme for Bounded Time Constraint in Delay Tolerant Networks

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Published online: 27 April 2017

Abstract In parallel with lots of research to improve message delivery rate in Delay Tolerant Networks (DTN), additional application specific requirements are demanded to deploy them in the real world. Among many requirements, we focus on desired delivery ratio within required deadline in DTN. To achieve this, we propose an adaptive forwarding algorithm primarily based on well-known DTN algorithm, Spray and Wait. Unlike conventional static forwarding schemes, the number of message copies and forwarding algorithm are dynamically adjusted according to the difference between current service level and given requirement in the proposed scheme. Furthermore, analytical model and recorded history on a node are used sequentially depending on availability of parameters to meet application specific requirement. Finally, simulation results demonstrate that our proposed algorithm can meet given requirement with lower resources consumption than existing protocols in varying network conditions.

Keywords Delay Tolerant Networks · Bounded delay · Spray and Wait

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1 Introduction

Delay Tolerant Networks (DTN) has been proposed to deliver data in partially connected network where there is no end-to-end path between source and destination due to frequent and unpredictable node's mobility. Although DTN is entirely different from the typical communication networks in that end-to-end delay is not considered as one of the most important criteria. In order to make use of mobility in an efficient way, different emerging applications are considering this approach as network architecture. Mobile social networks and vehicular ad hoc networks are the good promising applications. For such networks, typical store-and-forward approach fails to work due to no guarantee for the end-to-end path. Thus, in recent years, a variety of routing protocols for DTN has been proposed while being based on a novel structure of store-and-carry. The important consideration in these routing protocols is to either increase the delivery ratio [1, 2] or keep delivery delay minimum [3, 4]. In parallel with lots of research to accommodate general requirement, application specific requirements have emerged in DTN recently. For example, several practical applications including content or advisement distribution in vehicular ad hoc networks and information dissemination in military network require bounded delay in DTN by limiting allowed delay. In such type of applications, data should be delivered within the deadline. Therefore, such deadline constraint as well as desired delivery ratio should be taken together while developing a new routing protocol.

To handle this research challenge, a few research have been conducted in DTN. For instance, Ishimaru et al. [5] proposed multiple InfoBoxes for the collection or dissemination of data from user at different sightseeing spots. However, this centralized multiple InfoBoxes approach demands additional time to set up utilities. Thus, it is not applicable in DTN due to uncertain connectivity caused by the frequent network partitions. Density Adaptive routing With Node deadline awareness (DAWN) [6] was proposed to increase the packet delivery ratio within deadline by being aware of density as well as transmission behaviors of neighboring nodes. However, due to high dependency on measurement record, their operations cannot be ensured at the early stage in network configuration where there are not enough measured data. Thus, a protocol that is mostly independent on parameters in networks is desirable until networks become stable.

Based on above deficiency, we need fully distributed and adaptive scheme according to current network environments. To achieve this goal, we have previously proposed new routing protocol [7] based on well-known Spray and Wait model which works independently with network information. More detailed, the proposed delay bounded routing protocol solely is based on the analytical model of Spray and Wait so as to adjust the number of message copies depending on how much packets meet the requirement while considering the delivery probability of node. This approach is particularly suitable for homogenous network where whole nodes move under the same mobility patterns in a given network space. However, real scenarios indicate different pairwise contact rates. It is thus suboptimal for non-identical mobility pattern to determine the correct number of message copies in order to achieve a desired delivery ratio within given deadline. In addition, the allocation of message copies cannot suit aforementioned routing situation. Another issue is applicability of analytic model scheme that cannot reflect the varying network parameters rapidly. Therefore, it is required to extend the current scheme to solve mentioned problems by reducing the strong dependency on analytical model. To achieve this, in this article, we propose new routing scheme and forwarding strategy to consider the gap between parameters in analytic model and current networks. In other words, a measurement-based approach is employed to decide the proper number of message copies for more accurate and realistic deployment under non-identical mobility pattern. By the help of the proposed scheme, we can reduce the number of message copies so low complexity in the aspects of processing time and power consumption for packet delivery at the intermediate nodes is achieved. In addition, the longer network lifetime make more nodes operable so more nodes perform delivery process in low complexity.

The main contributions of this paper are summarized as follows.

1. A new practical model utilizing the measured real output and results is consequently adopted following by the analytical model. By doing so, accuracy is improved by reducing gap between analytical model and real deployment.
2. A new proportional message spray is further incorporated into the forwarding mechanism so as to bring substantial increase in the desired performance and reduce the resource consumption.
3. Extensive simulations are performed in different scenarios for more accurate analysis. This is done by additionally selecting comparable protocols and networks environments. Thus, the impact of several parameters are easily recognized.

The rest of this paper is organized as follows. In Sect. 2, we present the related work including our previous research result. The proposed scheme and performance evaluation though simulation are described in Sects. 3 and 4, respectively. Finally, the conclusion is given in Sect. 5.

2 Related Work

Recently, several routing protocols have been proposed to meet the requirements of various applications for DTNs. Among them, replication based routing schemes have been found to provide high delivery rate and short delivery delay in many situations. For example, one of most referred epidemic routing [1] is an approach that floods the message throughout the network in order to achieve maximum performance when loose constraints exist on network resources. However, in realistic settings where the resources (e.g., buffer space, bandwidth and battery) are limited, its scope of applicability for resource constraint networks is severely limited. Further, under high traffic load condition, it suffers from extreme congestion and message drops due to the huge number of redundant message copies. It results in significant degradation for its performance and scalability.

To alleviate these shortcomings of epidemic routing, the controlled replication or spraying based routing protocols have been proposed and extended as some variants in [8–10] to deliver a message by aiming to achieve acceptable performance. The key features of them are to exploit node characteristics, for example, encounter history, mobility pattern, and network topology, in order to rationalize the resource consumption by generating only a small number of message copies than epidemic routing. However, despite controlled replication, most of these schemes hardly achieve desired performance due to dependency on fixed number of message copies allocated during message creation phase.

This recognized problem leads to research work in developing adaptive routing algorithms that achieve not only high performance but also high resource efficiency. Furthermore, adaptive scheme can be used to meet application specific requirement due to their flexibility. As mentioned before, we have focused on delivery ratio within the deadline which is expected to be widely deployed for applications with more sensitive time property. However, to the best of our knowledge, this problem has hardly been addressed excepts for few literatures. In [11], distribution of the message copying process was divided into multiple periods. In each period, source node sprays a certain number of message copies until message is delivered or its TTL expires. The intentions of this scheme is to deliver the messages with small number of message copies. In addition, the allocation of message copies without considering destination dependent information can be easily shown sub-optimal when the deadline of message is limited. Similarly, the number of message copies is determined by dependency on the urgency of the delivery deadline in [12]. In their work, a source node sprays a small number of message copies than necessary ones. If the delivery does not happen for some time then additional message copies are sprayed to increase the probability of delivery. Accordingly, the average number of message copies used for each message will be reduced. Fen Hou et al. [13] proposed a new adaptive scheme by adjusting the probability of replicating a message. By the help of the adjustment controlled by the number of existing message copies in the network, the proposed scheme contributed to reduce the number of message copies and achieve acceptable balance between delivery delay and number of message copy. Through simulation results, it is noticeable that power consumption and buffer occupation decrease as compared to conventional scheme, epidemic routing. A New Adaptive Routing Proposal (NARP) [14] was proposed to use the message forwarding probability scheme by arranging the dropping sequence sequence with priority which is adaptively determined by average hop count and latency. Guan et al. [15] proposed a Social Relationship based Adaptive Multiple Spray-and-Wait routing algorithm (SRAMSW) adjusts the number of message copies based on their residence times in the node via buffer management and selects forwarders based on the social relationship adaptively. Thus, message congestion in the buffer and successful delivery rate are improved by reducing queuing time in the buffer.

In [16], the authors evaluated and compared the performance of different routing protocols in a many-to-one communication opportunistic network scenario for short and long distances between source and destination nodes. Similarly, the authors proposed Multicent, an incentive scheme for DTN routing that can encourage nodes to follow the two aspects of cooperation to realize different performance objectives in [17]. The scheme also realizes adjustable QoS for packets of specific sources, destinations, or source-destination pairs. The current and future deployments of Contact Graph Routing is discussed in [18].

Finally, the major addition to our previous work [7] includes the following. Firstly, we have developed a measurement-based approach to cover the gap between parameters (i.e., the number of message copies) in analytical model and current networks in order to better suit the more realistic mobility situations. Secondly, a proportional message spray is incorporated with the aim to minimize spraying time. Specifically, a node distributes more number of message copies to an encountered node, which has the lowest gap with desired requirements and does not have the message. This process continues until one message copy remains in each node. This results in faster spraying compared to the source spraying (i.e., previous work). Furthermore, the faster message copies are sprayed, the early the delivery process start and higher is the probability that the message is delivered within given deadline.

Although many routing schemes were proposed to meet the deadline consideration in DTN, often they suffer from the issue of incorrect number of message copies calculation which leads to low desired delivery within deadline or a waste of network resources. The main contribution of this work is to propose a new practical model utilizing the real output is consequently adopted followed by the analytical model for more accurate and realistic deployment. Therefore, a practical model utilizing the measured real output is proposed to calculate the number of message copies within deadline.

3 Proposed Routing Protocol

3.1 Network and Flow Model

A flow, denoted by F_i, is a set of message stream from a source node i to a destination, dst_i. For the simplicity, we assume that there is one flow between one source and dst_i. The message deadline is denoted by D_i. In addition, each flow has a required packet delivery ratio, P_i, which indicates the total number of packets $P_i \times Total\_Sent\_Pkts$ delivered to the dst_i within D_i. C_i represents the number of packets delivered to dst_i within D_i till this point. So, $F_i = \{i, dst_i, D_i, P_i, C_i\}$. (For instance, any flow can be considered that more than 80% packets issued by a source in the flow should be delivered to the destination within 150 min, but 70% packets satisfy the desired requirements). In this case, F_i is defined as $\{i, dst_i, 150min, 80, 70\%\}$. Also, the proposed scheme operates in a round way. That is, C_i is reported and reset when every round is expired rather than any packet is delivered.

3.2 Overview of Operations

In this section, we first briefly describe the key idea and the rationale behind the design of the routing protocol. Secondly, we present the design of proposed scheme in detail.

The operations of proposed routing algorithm include two phases named (i) the analytical-based model and (ii) measurement-based model. In the analytical-based model, the number of message copies for each message is calculated based on our previous work [7] due to unavailable of network parameters on the nodes. During this phase, the number of message copies depends on how many packets meet the desired requirements. Further, larger number of message copies are produced where C_i is less than P_i. Also, whenever a node encounters another node, it replicates data packet depending on the number of message copies. During this phase, each node builds the encounter record for F_i, denoted as ER_i, for each encountered node which will be used to predict the future encounters. ER_i represents the entry for (C_i, T_i) where T_i refers to how much time was taken for corresponding connection among whole connection time. Thus, T_i can be represented by $T_i = \frac{D_i}{I_i} / \sum_j^n (\frac{D_j}{I_j})$ where I_i refers to inter-meeting time which represents the time difference between two consecutive contacts between i and dst_i while D_i indicates the connection time between i and dst_i. In this equation, n is set to total number of node encounter by node i. So, T_i indicates that how much time was taken for all connection time. The information is further used to decide the number of message copies. But, there is still one problem to record ER_i at the intermediate node. This is because the dst_i reports C_i value to the source i only. This problem can be solved by including intermediate node's id and remaining time in the header. After the dst_i receive the data packet, it replied to both the source and intermediate node for number of packets delivered within deadline, respectively. By this way, ER_i entry on a source and intermediate node is created.

In the measurement-based model, a number of message copies is determined based on both P_i and C_i. Also, instead of single message spray in analytic-based model, if more than

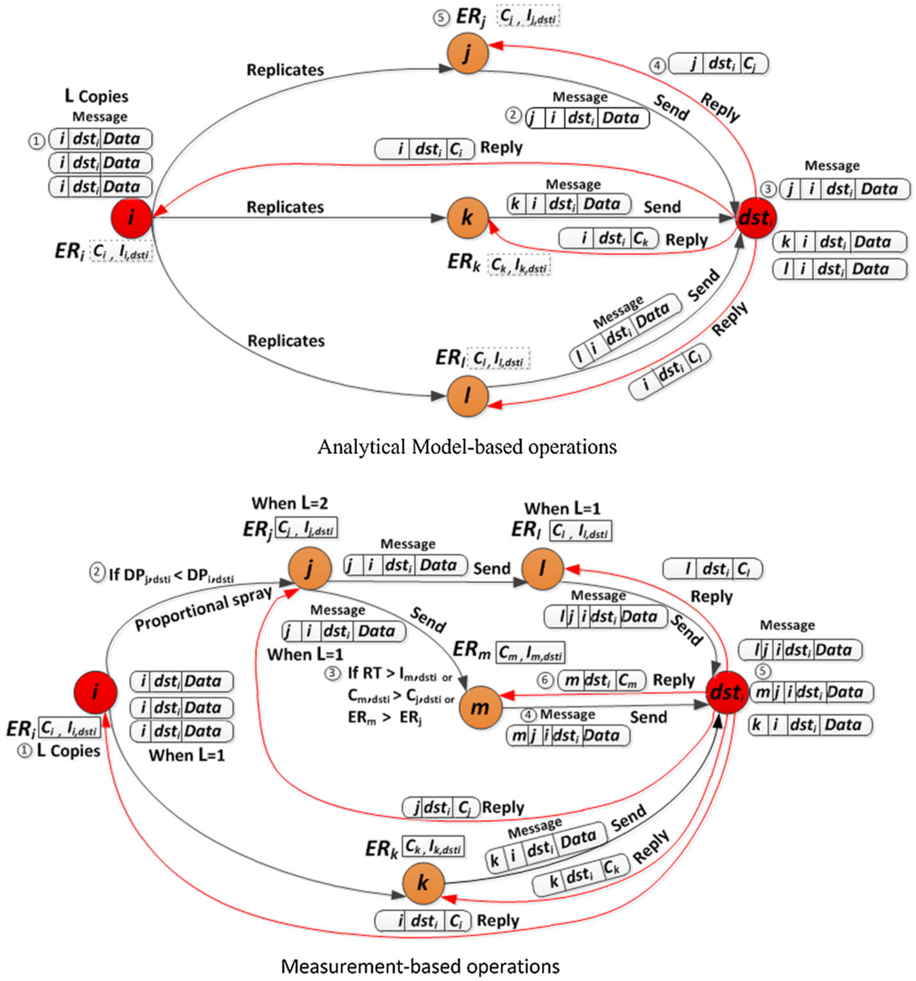

Fig. 1 Proposed forwarding operations

one message copies are held by a node, the proportional message spray is applied. The two different operations of the proposed routing protocol are illustrated in Fig. 1. The main difference between two cases is recognized by the proportional message spray as depicted third operation in measurement-based operation. This illustrates the multiple message spray to the node that is expected to have higher potential to deliver data to the dst_i.

3.3 Dynamic Adjustment of Message Copies

Like analytical-based model, we propose a new algorithm to find the proper number of message copies in an adaptive way. In every round, each node collects *ER* with the message copies to adjust the number of message copies as shown in Algorithm 1 and choose new $\bar{L}$.

Algorithm 1 Find Proper Number of Message Copies at the Source

1: $L_i[k]$ = message copies at current round, k
2: $\bar{L}_i[k+1]$ = message copies at next round, k+1
3: **if** $(C_i[k] < P_i)$ **then**
4: $\quad \bar{L}_i[k+1] \leftarrow L_i[k] + L_i[k] \times \lceil \log P_i[k] - \log C_i[k] \rceil$
5: **else**
6: $\quad \bar{L}_i[k+1] \leftarrow L_i[k] - L_i[k] \times \lfloor \log C_i[k] - \log P_i[k] \rfloor$
7: **end if**

According to Algorithm 1, for each message flow F_i on source node i with required packet delivery ratio P_i in round k. If the source node i detects that current quality level $C_i[k]$ less than P_i, then the number of message copies increases by considering gap between the required packet delivery ratio and the current quality level. Similarly, if the current quality level $C_i[k]$ at source node i is larger than required packet delivery ratio P_i, the number of message copies is reduced.

3.4 Message Forwarding Mechanism

At the measurement-based model, each node makes forwarding decisions by using the knowledge of *ER*. The message forwarding decisions are primarily based on the delivery potential (denoted as *DP*) value of the encountered node for the destination and the number of message copies. To achieve the desired delivery ratio, the node can spray the message copies proportionally to different encountered nodes according to their *DP*, regarding the destination. Therefore, when a node encounters other node, it divides the message copies between them proportionally according to their *DP* values, which are calculated by considering requirement and on their *ER*. When the number of message copies on a node becomes one, a node switches from proportional spray to the previous forwarding rule discussed in [7].

3.4.1 Delivery Potential (DP) Calculation

The two inputs to the *DP* are (i) current quality level and (ii) required packet delivery ratio. Each node calculates the *DP* as the difference between the P_i and the C_i, as given in Eq. 1 below. Thus, higher value indicates a node does not provide satisfactory service level. On the other hand, this node is regarded to maintain the acceptable level.

$$DP_{i,dst_i} = P_i - C_i \tag{1}$$

The goal of Eq. 1 is to emphasize both P_i and C_i by making adaptive forwarding decision for proportional message spray. The main reason of altering forwarding probability is to adapt corresponding continual changes of nodes quality level with the desired message requirement. Therefore, the messages are no longer forwarded with a constant probability but with a lower or higher *DP* depending on the message requirements and the current quality level of the node. Each node in the ER_i can take part in proportional message spray only, if its DP_{j,dst_i} is less than the sending node i. Similarly, the number of message copies to be sprayed to node j which is described in proportional message spray given in Eq. 2 below.

3.4.2 Proportional Message Spray

The proportional message spray is applied when a node holds more than one message copies. The basic idea is to proportionally spray the message copies to the encountered node according to our defined *DP* for the destination. If the *DP* of the encountered node *j* is less than the sending node, then the number of messages to be sprayed to node *j* denoted by $S_{i,j}$, is computed by using the following Eq. 2, where *L* represents the number of message copies at source node *i*.

$$S_{i,j} = \left\lceil L\left(\frac{DP_{i,dst_i}}{DP_{i,dst_i} + DP_{j,dst_i}}\right)\right\rceil \tag{2}$$

This equation guarantees that the larger number of message copies is sprayed to the encountered node that has the smallest gap with the desired requirement. Furthermore, proportionally spraying entitles encounter nodes to be responsible for further spraying when it holds more than one copy of a message. Furthermore, the faster the copies are sprayed, the earlier the delivery process starts. Thus, it results in higher probability of message delivery by given deadline. The complete forwarding mechanism is summarized in Algorithm 2.

Algorithm 2 Forwarding Mechanism

Input: current message holder i, encountered node j, message M
  T_{src} = delay from source to i
  M_r = Number of relay node for M
  RT_j = D_j-T_{src}- elapsed time from message holder i to j
  $\mathrm{C}_{j,\ dst_i}$ = current quality level at node j for dst_i
  $\mathrm{I}_{j,\ dst_i}$ = inter-meeting times between j and dst_i
Output: forward or not forward
Whenever node i encounters j
for each message on node i **do**
  update the message RT_i
  if $M_r \leq Threshold$ **then**
    if $(L > 1)$ **and** $(DP_{i,\ dst_i}) > (DP_{j,\ dst_i})$ **then**
      Apply proportional message spray
    else if (($\mathrm{C}_{j,\ dst_i} > \mathrm{C}_{i,\ dst_i}$) Or (($ER_j > ER_i$) And ($RT_j > \mathrm{I}_{j,\ dst_i}$))) **then**
      i forwards M to j
    else
      i keeps M
    end if
  else
    i keeps M
  end if
end for

4 Performance Evaluation

In this section, we first present the simulation setup and the performance metrics. After that, we briefly describe the comparable routing protocols. Finally, we evaluate the performance of the proposed routing scheme with comparable routing protocols.

4.1 Simulation Enviroments

We used the Opportunistic Network Environment (ONE) [19] simulator to evaluate the performance of the proposed routing scheme. ONE simulator is capable of generating node movement using different mobility model such as random walk and map based movement for the quicker and easy protocol evaluation. It also produce a variety of reports from message node movement to general statics such as delivery ratio, delivery delay and overall protocol overhead. We consider the Helsinki city scenario with covering area of 4500 m $\times$ 3000 m with variable number of nodes. In the proposed scenario, we setup 125 nodes consisting of pedestrians, cars and trams moving inside the Helsinki city. All the nodes are mobile using a Bluetooth interface at 250 kbps bandwidth and with transmission range of 10 m. There are 80 pedestrians who move at speed varying between 0.5 and 1.5 m/s. The remaining 40 nodes include cars running at 10–50 km/h and 5 nodes are trams moving on predefined path at 25–36 km/h speed. Data messages are generated by source node after every 35 s. The TTL of the data messages are set to 50 min without any special mentioning. The mobility pattern of all these nodes follows map based movement. Each simulation runs for 12 h with 30 min initial warm-up time. The main parameters settings are summarized in Table 1.

4.2 Performance Metrics

To evaluate the performance of DTN protocols, we introduce the following three metrics. The definition of these metrics is presented as follows:

Delivery ratio The percentage of messages delivered to the destination within given deadline over generated messages.

Average latency It refers to the time difference between the creation time and the reception time of the messages.

Overhead ratio It is defined to be the number of relay operations (excluding the delivery action) over the total number of generated messages.

4.3 Comparable Protocols

Based on the above settings, we compare the proposed routing scheme with the following benchmark routing protocols.

Table 1 Parameter settings

Parameter name	Value
Simulation area	4500 $\times$ 3000
Number of nodes	125 $\sim$ 245
Simulation time	12 h
Message size	500 kb
Warm-up time	30 min
Transmission range	10 m
Desired delivery rate	0.8
Message generation interval	35 s
Message TTL	50 $\sim$ 150 min
Time for one round	3 min

Epidemic In this routing scheme, packet generated by a node are forwarded to all the encountered node without employing any control scheme.

Spray and Focus [9] Source node symmetrically sprays the message copies to every encountered node that does not have a copy of the packet, and the number of message copies are limited to certain *L*. After, all the copies are sprayed, each of them is forwarded independently based on comparative utility forwarding approach. In our simulation setup the number of message copies for Spray and Focus is set to 10 percent of the total number of nodes.

4.4 Simulation Results

For the first simulation results, we set the node buffer size to 50 MB under varying the message *TTL*. Figure 2a shows the delivery ratio of comparable routing protocols according to message *TTL*. It can be seen that both the packet delivery ratio and the average latency of all protocols increase by giving more *TTL* to the packet. This is because a longer *TTL* allows packets to stay for a longer time in the network so messages have

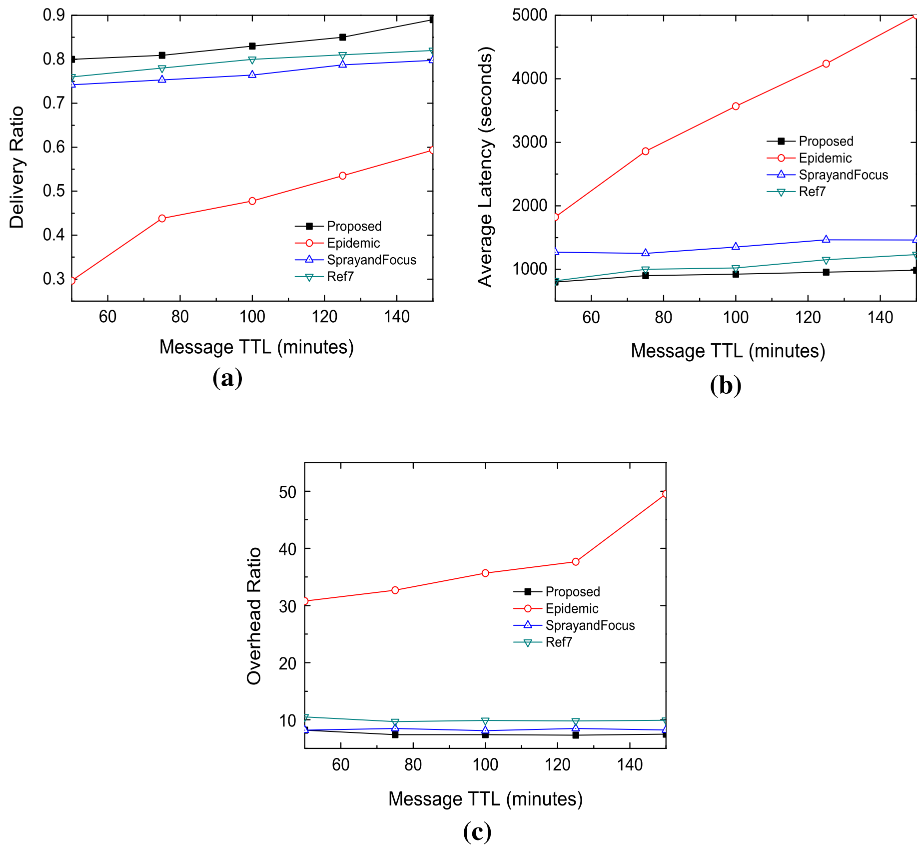

Fig. 2 Performance of the protocols, under different message TTL values. **a** Delivery ratio as a function of message TTL. **b** Average latency as a function of message TTL. **c** Overhead ratio as a function of message TTL

higher chances to be delivered subsequently. The proposed scheme maintains the least difference value to the target delivery ratio, 0.8 for all values of *TTL*. There are two main reasons. First, unlike other protocols, we adjust the message copies value while considering both user requirements and current quality level. So, it is possible to maintain almost similar value to predetermined requirement. Second, proposed scheme takes advantage of encounter record that steers the forwarding of a messages while lower value in other protocols is caused by their inefficient forwarding through passing a message copy to every node without considering destination dependent information. We can see that the proposed scheme achieves the shortest average latency among all the comparable routing protocols in Fig. 2b. Specifically, our dynamic adjustment of message copies plays the important role in this result. We generate more copies for message with a short *TTL* while others do not consider the difference between messages **TTL** into account. With respect to the overhead ratio in Fig. 2c, the proposed scheme has a slightly higher overhead ratio than Spray and Focus when the *TTL* is smaller than 100 min. This negative aspect is caused by the more copies for a message with a short *TTL*.

In the second set of simulation results, we set the message *TTL* to 150 min with varying the node buffer size. Figure 3a shows the assessment of delivery ratio for increasing buffer

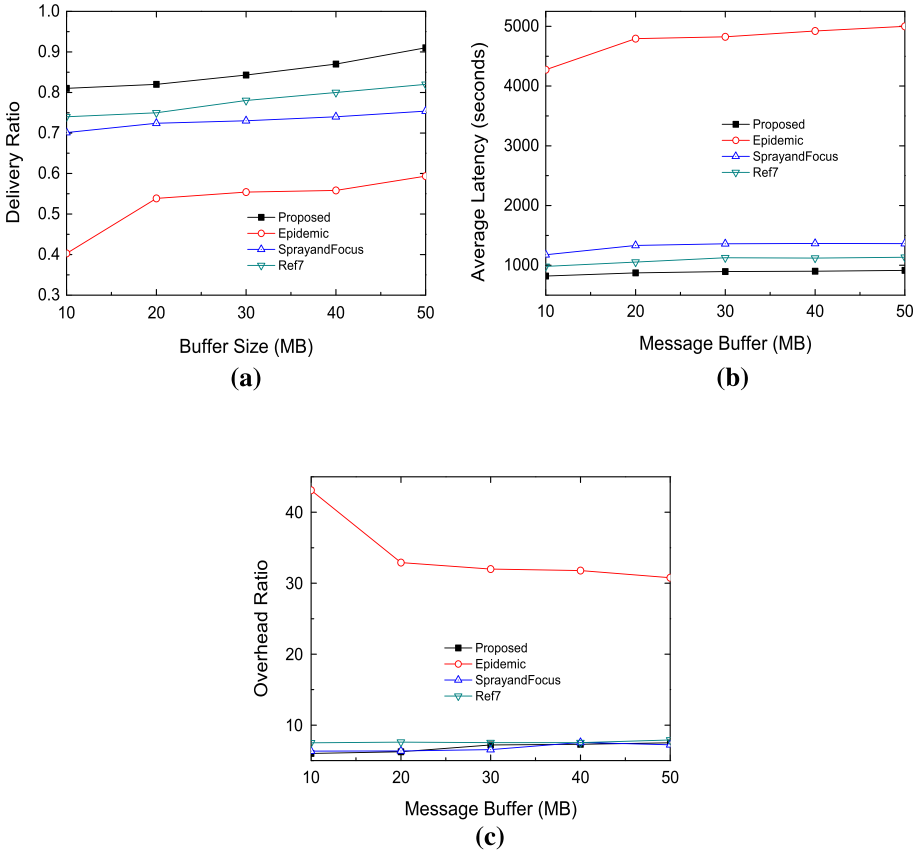

Fig. 3 Performance of the protocols, under different buffer sizes. **a** Delivery ratio as a function of buffer size. **b** Delivery ratio as a function of buffer size. **c** Overhead ratio as a function of buffer size

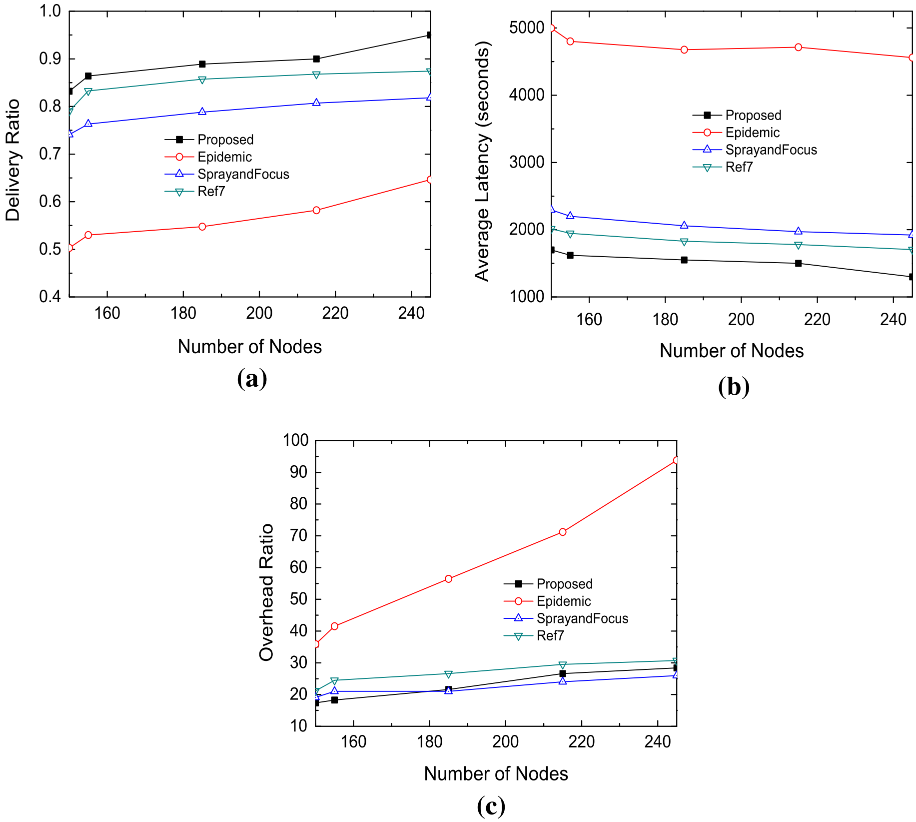

Fig. 4 Performance of the protocols, under different number of nodes. **a** Delivery ratio as a function of number of nodes. **b** Delivery ratio as a function of number of nodes. **c** Overhead ratio as a function of number of nodes

size. As the buffer size increases, both the delivery ratio and average latency of all routing schemes increases. This is because a lager buffer size allows them to accommodate more messages by reducing the probability of packet drop due to buffer overflow. However, messages are delivered later with a longer delay by staying longer in a buffer. It is notable that the proposed scheme outperforms all the other comparable routing protocols in terms of delivery ratio and average latency under all buffer sizes. This is because proposed scheme generates message copies based on the individual node performance which avoids many unnecessary redundant copies as compared to Spray and Focus that causes transmission reduction per delivery. This fact leads to increase the delivery rate. At the same time, a node prevents excessive buffer space through fewer message copies. Also, it consequently lowers the average latency of each message as illustrated in Fig. 3b. Another contribution comes from the proportional message spray in the forwarding method by reducing the number of forwarding nodes that utilize buffer space. However, as observed in Fig. 3c, the overhead ratio of the proposed scheme is relatively higher than Spray and Focus. This result comes from employing proportional message spray instead of binary spray in the forwarding. However, such forwarding mechanism brings shorter time, on the other hand, much larger overhead than that of Spray and Focus.

In the third set of simulation results, we set the node buffer size to 50 MB with the number of nodes. The main goal of this scenario is to observe that how each protocol works under different level of node density. It is observed that encounter opportunities and the total network buffer capacity increase as the number of nodes increases. This supports increased the delivery ratio of the protocols and the reduced average latency as shown in the Fig. 4a, b. We also note that delivery ratio of proposed scheme is higher than others. The key reason is that we adjust the message copies based on the delivery ratio of the message, which alleviates the required number of message copies compared to all existing schemes. Another reason is that the number of message copies is reduced when the network becomes denser due to encounter record which means fewer relay operations. It leads to reduce message loss as well as increase the delivery ratio. It indicates that the encounter record in the proposed scheme greatly affect the message copies used. At the same time, it helps to maintain desired delivery rate and average delivery delay. The associating side effect, that is, increasing overhead ratio, is illustrated in Fig. 4c.

5 Conclusions

In this paper, we proposed an adaptive routing algorithm for DTNs that considered both the desired delivery ratio of a message and the node's current quality level to distribute the number of message copies. A new algorithm takes the advantage of the local encounter record which evaluates the node quality through the number of packet delivered within deadline. Thus, it leads to low complexity in the amount of processing and power consumption by the reduced number of message copies. Finally, we provided simulations results to evaluate the performance of the proposed scheme under different scenarios. The results demonstrates that the proposed scheme achieves better performance in terms of message delivery ratio and average latency than comparable routing protocols in all scenarios.

Acknowledgements This work was supported by Basic Science Research Program (2015R1D1A1A01056979) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education. Also, it was supported by Research Incentive Fund (RIF Activity Code: R17058) by Zayed University, Abu Dhabi, UAE. A preliminary version of this paper was presented at the 9th ACM International Conference on Ubiquitous Information Management and Communication, 2015.

References

1. Vahdat, A., & Becker, D. (2000). Epidemic routing for partially connected ad hoc networks. *Technical Report. CS-2000-06, Duke University*, Durham, USA.
2. Lindgren, A., Doria, A., & Schelen, O. (2003). Probabilistic routing in intermittently connected networks. *ACM SIGMOBILE Mobile Computing and Communications Review*, *7*(3), 19–20.
3. Balasubramanian, A., Levine, B. N., & Venkataramani, A. (2010). Replication routing in DTNs: A resource allocation approach. *IEEE/ACM Transactions on Networking*, *8*(2), 596–609.
4. Spyropoulos, T., Psounis, K., & Raghavendra, C. S. (2005). Spray and Wait: An efficient routing scheme for intermittently connected mobile networks. In *Proceedings of ACM SIGCOMM workshop on Delay Tolerant Network*, (pp. 252–259), August 2005.

5. Ishimaru, Y., Sun, W., Yasumoto, K., & Ito, M. (2010). Dtn-based delivery of word-of-mouth information with priority and deadline. In *Proceedings of 5th international conference on mobile computing and ubiquitous networking*.
6. Fu, Q., Krishnamachari, B., & Zhang L, L. (2013). DAWN: A density adaptive routing for deadline-based data collection in vehicular delay tolerant networks. *Tsinghua Science and Technology*, *18*(3), 230–241.
7. Abbas, A., Lee, C., & KIM, K. (2015). Delay bounded spray and wait in delay tolerant networks. In *Proceedings of 9th ACM International Conference on Ubiquitous Information Management and Communication*, January 2015.
8. Spyropoulos, T., Psounis, K., & Raghavendra, C. S. (2008). Efficient routing in intermittently connected mobile networks: The multiple-copy case. *IEEE/ACM Transaction on Networking*, *16*(1), 77–90.
9. Spyropoulos, T., Psounis, K., & Raghavendra, C. S. (2007). Spray and focus: Efficient mobility-assisted routing for heterogeneous and correlated mobility. In *Proceedings of 5th annual IEEE international conference on pervasive computing and communications workshop*, pp. (79–85), March 2007.
10. Nelson, S. C., Bakht, M., & Kravets ,R. (2009). Encounter-based routing in DTNs. In *Proceedings of the 28th conference on computer communication*, pp. (846–854), April 2009.
11. Bulut, E., Wang, Z., & Szymanski, B. K. (2010). Cost effective multi-period spraying for routing in delay tolerant networks. *IEEE/ACM Transactions on Networking*, *18*(5), 1530–1543.
12. Bulut, E., Wang, Z., & Szymanski, B. K (2008). Time dependent message spraying for routing in intermittently connected networks. In *IEEE GLOBECOM*.
13. Hou, F., & Shen, X. (2009). An adaptive forwarding scheme for message delivery over delay tolerant networks. In *IEEE GLOBECOM*.
14. Mamoun, M. (2013). New adaptive routing proposal for DTN. *International Journal of Computer Applications*, *82*(9), 37–40.
15. Guan, J., Chu, Q., & You, I (2017). The social relationship based adaptive multi-spray-and-wait routing algorithm for disruption tolerant network. *Mobile Information Systems*, *2017*, 1819495.
16. Spaho, E., Bylykbashi, K., Barolli, L., Kolici, V., & Lala, A. (2016). Evaluation of different DTN routing protocols in an opportunistic network considering many-to-one communication scenario. In *Proceedings of IEEE 19th international conference on network-based information systems*, September 2016.
17. Chen, K., Shen, H., & Yan, L. (2015). Multicent: A multifunctional incentive scheme adaptive to diverse performance objectives for DTN routing. *IEEE Transactions on Parallel and Distributed Systems*, *26*(6), 1643–1653.
18. Araniti, G., Bezirgiannidis, N., Birrane, E., Bisio, I., Burleigh, S., Caini, C., Feldmann, M., Marchese, M., Segui, J., & Suzuki, K. (2008). Contact graph routing in DTN space networks: Overview, enhancements and performance. In *IEEE GLOBECOM*.
19. Keranen, A., Ott, J., & Karkkainen, T. (2015). The ONE simulator for dtn protocol evaluation. *IEEE Communications Magazine*, *53*(3), 38–46.

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