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Research Article

EpSoc: Social-Based Epidemic-Based Routing Protocol in Opportunistic Mobile Social Network

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In opportunistic networks, the nature of intermittent and disruptive connections degrades the efficiency of routing. Epidemic routing protocol is used as a benchmark for most of routing protocols in opportunistic mobile social networks (OMSNs) due to its high message delivery and latency. However, Epidemic incurs high cost in terms of overhead and hop count. In this paper, we propose a hybrid routing protocol called EpSoc which utilizes the Epidemic routing forwarding strategy and exploits an important social feature, that is, degree centrality. Two techniques are used in EpSoc. Messages' TTL is adjusted based on the degree centrality of nodes, and the message blocking mechanism is used to control replication. Simulation results show that EpSoc increases the delivery ratio and decreases the overhead ratio, the average latency, and the hop counts as compared to Epidemic and Bubble Rap.

1. Introduction

Opportunistic mobile social network (OMSN) [1–4] is a promising networking model for data dissemination. In the OMSN, mobile nodes grab the opportunity of encountering the peer (they are in the communication range of each other) to forward the data. The OMSN incurs intermittent and disruptive connectivity due to node mobility. To tackle with this complex environment, the store-carry-forward scheme is applied in the OMSN. If no connection is available at a particular time, a mobile node stores data in its buffer and carries them until it encounters other mobile nodes to forward the data [5–8]. Various approaches have been proposed to address the information delivery problem in the OMSN such as in [9–12]. The main concerns of OMSN routing approaches are yielding high delivery ratio, low delay, and low overhead or cost on networks and nodes.

Flooding is one of the dominant schemes to disseminate data in the OMSN [13]. Each message will be flooded to every node in the network. Multiple copies of each message are generated and spread in the network. Epidemic [9] routing protocol is the flooding-based routing protocol. When two nodes encounter, they exchange all of their messages. This results in messages spread over the whole network by pairwise contacts between two nodes. If no buffer constraints are applied, Epidemic represents the upper bound in message delivery and latency. Epidemic routing is used as a benchmark and a reference for the most of other routing protocols in the opportunistic network. The main drawback of the Epidemic scheme is its high overhead. Many schemes are proposed to decrease the overhead in Epidemic-based approaches by limiting the number of message replicas [14–16]. An effective scheme to control replication spread is the vaccine [17]. It applies the antipacket mechanism to control replica distribution in Epidemic-based routing. In [18], a new scheme is proposed to control the replication of epidemically distributed information. Based on the vaccine scheme, signal distribution is early controlled by the fully immunized vaccine. In addition, a partially immunized vaccine is initiated when there is a local-forwarding opportunity to vaccine more packets.

In the OMSN, mobile devices are portable by humans so that social features of people can be exploited for networking purposes [19–21]. Social-based protocols utilize social properties of mobile users such as similarity, centrality, and friendship to improve routing efficiency in the opportunistic mobile social network. This is because social features are more stable and less changeable than other features like mobility patterns. HiBOp [22] and CiPRO [23] exploit the similarity social feature and the user's context information to forward data. LASS [24] takes into account the difference of members' activity within the node's community for data dissemination. In ML-SOR [25], node centrality (different types of centralities), the similarity between communities, and social ties are all exploited to effectively select the forwarding node. MCAR [26] exploits the preferred communities of people during their daily lives for effective information delivery. Direct (inside one community) and indirect (via different communities) contacts are considered in MCAR. In SPRINT-SELF [27], network and node overhead is decreased by exploiting social information of mobile users. The authors consider the social community of nodes and utilize it to predict future behavior based on contact history. In addition, they proposed a new mechanism to avoid selfish nodes for more improvements.

Social features are utilized widely for buffer management. Liu et al. [28] utilized social features and the congestion level to develop the forwarding strategy that drops the message with the minimum social link rather than random dropping. In SRAMSW [29], the buffer management mechanism is combined with social features to enhance the spray-based routing. Expired messages are deleted, successfully delivered messages are acknowledged, and messages are prioritized according to their spray times and residence time. In addition, three social features: centrality, similarity, and friendship, are adopted for better forwarding decision and to avoid the dead-end problem.

We hypothesize that combining social features with the Epidemic-based forwarding scheme improves the efficiency of routing in the OMSN. In this paper, we present an Epidemic-based Social-based routing protocol (EpSoc) that combines the advantages of the forwarding strategy used in the Epidemic routing protocol with the positive impact of exploiting social features. EpSoc exploits the degree centrality social feature to adapt the time to live (TTL) of the routed message. If a message is forwarded to a node which has higher degree centrality (socially active node), its TTL value will be decreased. If these messages are dropped in the active node when TTL is zero, the blocking mechanism is used to reject receiving replications of these messages.

The rest of this paper is organized as follows: the next section reviews the related work. We describe in detail our proposed algorithm EpSoc in Section 3. In Section 4, we introduce the performance evaluation and the discussion results. Finally, Section 5 concludes the paper.

2. Related Works

Delivering data to the destination at the right time with minimum resources is an optimal condition for any given routing protocols. Epidemic has optimal performance in terms of delivery ratio and latency. However, it suffers from high overhead cost. One of the solutions is to exploit social information to improve Epidemic-based routing protocols in the OMSN. Degree centrality is a social feature that is exploited widely in the literature to improve routing in the mobile social networks. For example, Bubble Rap [11] utilizes the mobile node's degree centrality to provide cost-effective routing as compared to Epidemic routing. Bubble Rap exploits two social and structural metrics, namely, centrality and community. It selects high centrality nodes and community members of destination as relays. In the Bubble Rap algorithm, nodes belong to different sizes of communities and have different levels of popularity (i.e., rank). Each node is assumed to have two rankings: global denotes the popularity (i.e., connectivity) of the node in the entire society and local denotes the popularity within its community. Messages are forwarded to nodes that have higher global ranking until a node in the destination's community is found. Then, the messages are forwarded to nodes having a higher local ranking within the destination's community.

Similar to Bubble Rap, CAOR [30] exploits degree centrality and similarity social features to improve routing. However, CAOR constructed autonomous communities based on common interest locations between mobile nodes. Members of a community with high centralities act as the home of this community. CAOR also has a mechanism to turn the routing between lots of nodes to the routing between a few community homes. It also applies the reverse Dijkstra algorithm to determine the optimal relays and compute the minimum expected delivery delay. In [31], cultural algorithm (CA), ant colony optimization (ACO), and social connectivity between users are combined to address the routing problem. Social metrics of nodes including degree and betweenness centralities are analyzed to support forwarding decision in the opportunistic network environment.

Besides exploited in the routing problem, social features were also applied to solve different type of problems. For example, works in [32] exploit social features (degree and betweenness centralities) to solve the throwbox placement problem based on the given graph. A user's degree is equal to the total number of its neighbors, and betweenness is the total number of shortest paths passing through the node. The work also introduced the concept of location degree to measure how many mobile users have the location as one of their top visited locations and the location betweenness to show how important the location is for the entire social graph. Social metrics such as degree centrality, social activeness, and community acquaintance are also applied to enhance data delivery in VSNs in [33]. The social interactions between nodes where nodes of similar interests or nodes belonging to the same community have greater probability to encounter each other. Social centrality is also utilized for congestion control in the postdisaster environment [34].

Unlike the aforementioned works, instead of considering community or homing structuring, our proposed protocol is based on the flooding-based forwarding strategy of Epidemic. This is because we intended to design our forwarding protocol to have high delivery ratio and low delay as the Epidemic-based forwarding strategy. Moreover, we also aimed to avoid extra time required to form and maintain the community structure. Thus, to decrease the overhead, we utilized degree centrality and adapted the message's TTL (Time to live) to control the forwarding nodes' activity. The message's TTL is considered in literature when developing efficient routing protocols. Miao et al. [33] proposed the adaptive multistep routing protocol for mobile delay-tolerant networks (MDTNs). Their aim is to get the balance between the delay and cost of message delivery. The time to live of the message is used in order to allocate the minimum number of copies necessary to achieve a given delivery probability. In [34], the authors considered the contact information of nodes and the time to live message's property to make route decision and improve performance. They built a replica distribution criterion between two encountered nodes based on residual messages' TTL. In our proposed solution, we do not limit the number of replicas but allow messages to be spread in the network and then we utilize degree centrality to decrease the TTL and consequently decrease the overhead. Also, the blocking mechanism is adopted in the active node to cancel receiving replications of the same message which is seen previously.

3. EpSoc Routing Protocol

EpSoc is the routing algorithm designed to decrease overhead in the Epidemic protocol by embedding social features in routing the message in the opportunistic network. To achieve this objective, we propose two mechanisms. First, the message's TTL is adapted based on degree centrality of the nodes in the OMSN. The second one is the message blocking mechanism that is used to prevent receiving the replications of runout TTL messages in active nodes.

3.1. Degree Centrality. Node centrality indicates the popularity of the node in the network, whereby node centrality in a social network is the reflection of its social relative importance [35]. A higher node degree centrality means the node connects with many numbers of nodes in the network. A degree centrality for a given node i can be calculated as follows:

$$\mathrm{DC}_i = \sum_{k=1}^{N} a(i,k), \tag{1}$$

where N is the number of nodes in the network and $a(i,k) = 1$ if a direct link exists between node i and node k and $i \neq k$.

We adopt the CWindow [11] calculation algorithm to calculate degree centrality. CWindow divides the day into time windows and calculates the average of nodes' degree over these windows to estimate the node's centrality. To decrease the processing overhead results from processing any changes of degree centrality, CWindow calculates the node's degree centrality at regular intervals instead of every time the centrality changes.

We pick the CWindow algorithm to calculate degree centrality because it takes into account the changes in node centrality over time and averages the node's centralities for few window intervals which is suitable for people's behavior in the OMSN. It is also used by other social-based protocols that consider the node's degree centrality such as Bubble Rap [11], Dlife [36], and SCORP [37].

3.2. EpSoc Forwarding Strategy. Figure 1 depicts the forwarding process in EpSoc, where two mechanisms are applied.

In Figure 1(a), node $N1$ encountered three nodes: $N2$, $N3$, and $N4$. $N2$ has higher degree centrality (DC) than $N1$. The TTL value of the forwarded messages to $N2$ is decreased by dividing it by the DC value of $N2$. We call these messages socially infected messages. Node $N2$ registers the ID of these messages as seen messages in its blocking register. Node $N2$ will drop the socially infected message when it expires. In Figure 1(b), the Epidemic forwarding strategy which we adopted in our algorithm causes replications of socially infected messages to be sent to node $N2$ from other nodes such as $N4$. In this case, node $N2$ will reject receiving the message with the reason that it is a seen message (its ID is stored in the block register).

Based on (1), the TTL value is adapted using the following equation:

$$\mathrm{TTL}_{\mathrm{new}} = \frac{\mathrm{TTL}_{\mathrm{old}}}{\mathrm{DC}_k} \quad \{\text{if } \mathrm{DC}_k > \mathrm{DC}_i\}. \tag{2}$$

The two combined mechanisms adopted in EpSoc enhance routing performance. If a node is socially active, it meets more nodes in the network and has a higher potential to deliver more messages. Decreasing messages' TTL value in active nodes results in releasing space in their buffers and increases the ability to deliver more messages. This will increase the delivery ratio. The blocking mechanism controls the replications by preventing decreased TTL messages from hitting again the previously traversed actives nodes. The result is decreasing network overhead. Regarding average latency, the messages that are delivered by active nodes have a shorter end-to-end delay compared to other messages delivered by lower activity nodes, so average latency will be decreased too. We conclude that decreasing message life socially by combining the message blocking scheme affects positively the performance of the Epidemic routing scheme in the OMSN.

3.3. Pseudocode of the EpSoc Message Forwarding. We used CWindow to calculate the centrality of the node. Each node N_i records the encountered nodes in the network. When node N_i encounters N_j, the degree centrality values are calculated using CWindow. Then, centrality values are exchanged between both nodes. N_i compares its centrality value DC_i with the N_j centrality value DC_j. If DC_j is greater than DC_i, which means that N_j is socially more active than N_i, then for each message m_i in the N_i buffer Buf_{N_i}, the TTL value $m_{i_{\mathrm{TTL}}}$ is decreased by dividing it by the node N_j centrality value DC_j. The ID of each socially infected message is registered in the N_j blocking register Block_{N_j}. The time complexity of the EpSoc forwarding algorithm is $\mathrm{O}(M)$, where M is the number of messages carried in the node's buffer and needed to be sent or forwarded.

Algorithm 1 shows the complete pseudocode of EpSoc.

4. Performance Evaluations

4.1. Data Set. We adopt the Cambridge experimental data set of haggle [38]. This data set includes traces of Bluetooth

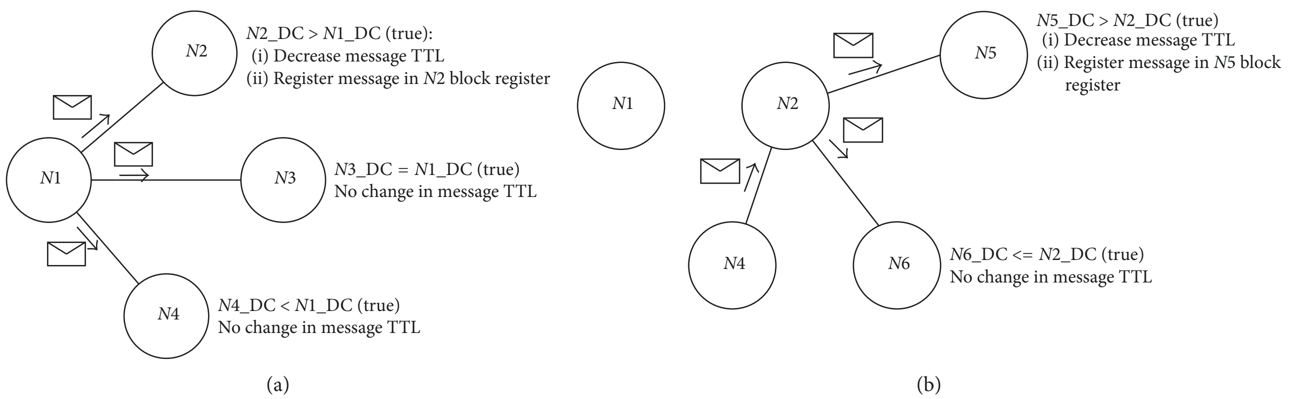

FIGURE 1: EpSoc forwarding scheme.

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For all N_i ∈ N
  if N_i encounter N_j
    Calculate DC_i, DC_j
    DC_i ⇆ DC_j
    For all m_i ∈ Buf_{N_i}
      if m_{i_ID} ∉ Block_{N_j}
        if DC_j > DC_i
          m_{i_TTL} ← m_{i_TTL}/DC_j
          Buf_{N_j} ← m_i forward message to N_j
          Block_{N_j} ← m_{i_ID}
        End if
      End if
    End for
  End if
End for
```

ALGORITHM 1: Pseudocode of the forwarding strategy in EpSoc.

sightings by groups of users carrying small devices (iMotes) for a number of days in campus environments. The experiments are conducted in the computer laboratory that includes the undergraduate first-year and second-year students and also some Ph.D. and postgraduate students which lasted for 11 days.

4.2. Simulation Setup. We use the opportunistic network environment (ONE) [39] simulator to evaluate our algorithm. Also, comparison with Epidemic and Bubble Rap routing protocols is included to measure the performance of our proposed algorithm EpSoc. We want to justify that the Epidemic algorithm performs better when considering social features in forwarding messages. The simulator settings are tabulated in Table 1.

In each experiment, we compare the performance of the protocols EpSoc, Epidemic, and Bubble Rap based on the following metrics.

4.2.1. Successful Delivery Ratio. It is the ratio between the number of delivered messages and the total number of created messages. The ideal value of the successful delivery ratio is 1.0 when all created messages are delivered to their destinations.

TABLE 1: Simulation settings.

Simulation time	987529 seconds
Interface	Bluetooth interface
No. of nodes	36
Transmit speed	250k (2 Mbps)
Mobility	Real trace data (Cambridge)
Buffer size	1, 5, 15, 25, 35, 45, and 55 MB
Routing protocols	Epidemic, EpSoc, and Bubble Rap
Message size	128k
Event interval	30 to 40 seconds
Initial message TTL	10 m, 30 m, 1 h, 3 h, 5 h, 12 h, 1 d, 1.5 d, 2.5 d, 3 d, 4 d, and 1 w

4.2.2. Overhead Ratio. It is the additional bytes that are sent for successfully delivering a message to a destination.

4.2.3. Average Latency. It is the average of the time elapsed between message creation and delivery.

4.2.4. Average Hop Count. It is the average of the number of hops that messages must take in order to reach the destination.

4.3. Experiments and Discussion. To evaluate our work, we will consider two features: buffer size and message TTL value. These two features have a high impact on routing performance in the OMSN. In our work, we affect these two features. We adjust the TTL value socially and use the blocking mechanism to manage buffer storing. Consequently, our experiments are to measure the performance of EpSoc when varying the TTL and buffer size. The comparison will be with Epidemic and Bubble Rap protocols.

4.3.1. Varying Buffer Size. For varying the buffer size, we fixed the value of TTL to 2.5 d. Figures 2–5 show the performance comparisons between EpSoc, Epidemic, and Bubble Rap in terms of delivery ratio, overhead ratio, average latency, and average hop count, respectively.

Figure 2 shows the delivery ratio with buffer size. Generally, for Epidemic, Bubble Rap, and EpSoc, increasing the

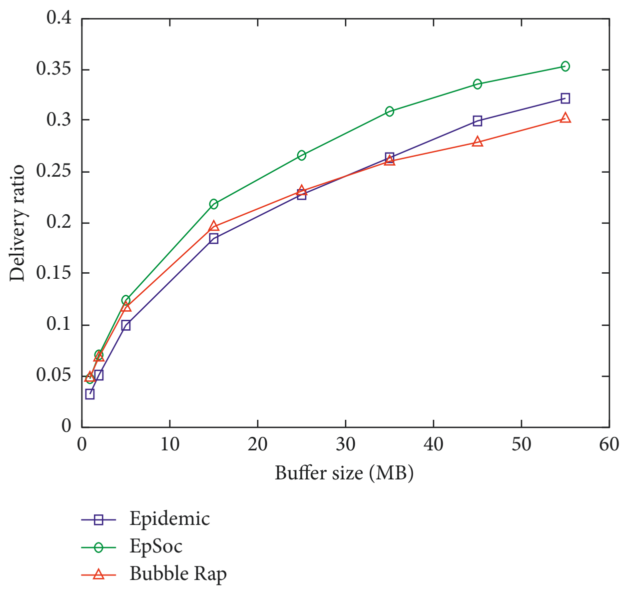

Figure 2: Delivery ratio versus buffer size.

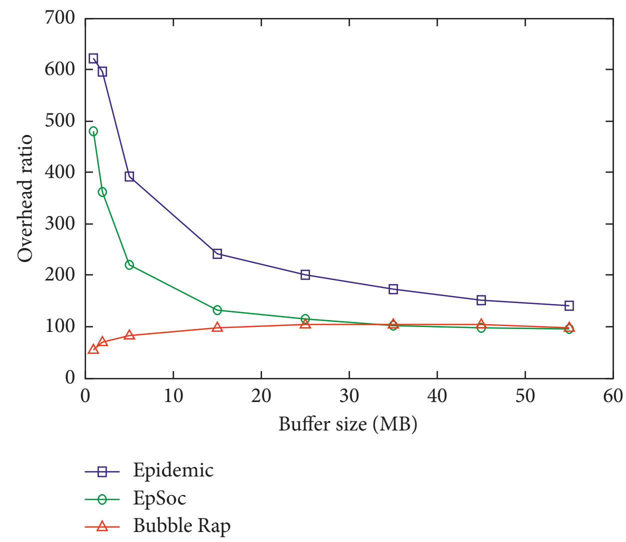

Figure 3: Overhead ratio versus buffer size.

buffer size will increase the delivery ratio. This is because more messages can be carried by intermediate nodes which consequently deliver more messages to destinations. Changing the number of delivered messages affects the delivery ratio, overhead ratio, average latency, and average hop count. Regarding the delivery ratio, it is clear that delivering more messages results in a higher value, while the decrease in delivered messages results in a lower value. In the lower buffer size scenario (1–25 MB), the delivery ratio of Epidemic is the lowest because of the redundancy. Bubble Rap and EpSoc outperform Epidemic due to utilizing social features. In higher buffer size scenarios (35–55 MB), Epidemic achieves higher delivery ratio than Bubble Rap. Larger buffer size alleviates the negative impact of dropping messages because of replication and enables Epidemic to deliver more messages. Our protocol EpSoc outperforms both Epidemic and Bubble Rap. Blocking runout TTL messages from being received by active nodes results in more space in their buffer and therefore can carry more different messages when encountering other nodes and later deliver them to destinations. In addition, the decrease of TTL of the messages that are forwarded to the more active nodes results in better utilization of the buffer's space. Decreased TTL message copies are dropped earlier enabling carrying more other messages. Active nodes deliver the message quickly. Therefore, the number of delivered messages is increased, and consequently, the delivery ratio is increased.

The relation of overhead ratio with buffer size is shown in Figure 3. When increasing the buffer size, the overhead is decreased for all algorithms. Regarding Bubble Rap, overhead is decreased with buffer increase because no replication exists. We observe from Figure 3 that both protocols Bubble Rap and EpSoc outperform Epidemic significantly and EpSoc outperforms Epidemic. We mentioned formerly that applying the strategy of blocking messages and decreasing TTL increase the number of delivered messages. In addition, the blocking message to be resent to active nodes decreases the number of replications in the network and hence decreases the forwardings. As a result, decreasing the forwardings and increasing the delivered messages decrease the overhead ratio in the network. Bubble Rap achieves lower overhead than EpSoc for lower buffer size scenarios (1, 2, 5, and 15 MB). This is because of two reasons: first, the replication and Epidemic strategy adopted in EpSoc, and second, low buffer size causes dropping relayed messages early due to buffer overflow which in turn decreases the efficiency of our proposed algorithm compared to Bubble Rap in terms of overhead. However, for larger buffer size scenarios (25, 35, 45, and 55 MB), EpSoc is more efficient and its overhead ratio is very close to that of Bubble Rap (for 35, 45, and 55 MB, it is slightly better than Bubble Rap).

Figure 4 shows that average latency for all the three protocols, which increases when the buffer size is increased. A low-sized buffer only relays low-latency messages which will reach their destinations quickly. On the other hand, a higher-sized buffer allows messages to be carried for a longer time which contribute to a higher average latency. EpSoc decreases the average latency significantly. EpSoc optimizes the buffer usage where messages forwarded to active nodes have low TTL. With the low TTL, a relay node has more free space for new messages in its buffer as the buffer quickly dropped the old messages.

In Figure 5, the average hop count is recorded. The average hop count increases when the buffer size is increased. Epidemic has more hop count which indicates more nodes experiencing the duplicated messages, whereas Bubble Rap has lower hop count because it prevents replication of messages. For EpSoc, the number of hop count is contributed by allowing replication as in Epidemic.

The worst achievement is because of redundancy. Bubble Rap does not apply replication so that it outperforms EpSoc. EpSoc achieves better average hop count than Epidemic. This is because of the message blocking strategy which decreases the number of replications in the network and hence decreases the forwardings.

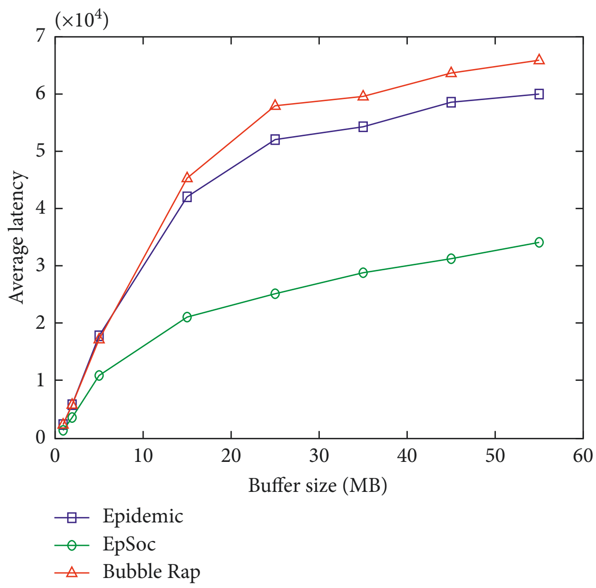

Figure 4: Average latency versus buffer size.

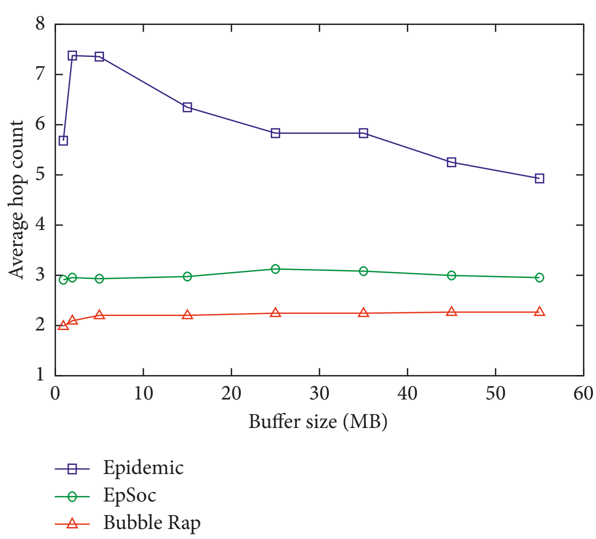

Figure 5: Average hop count versus buffer size.

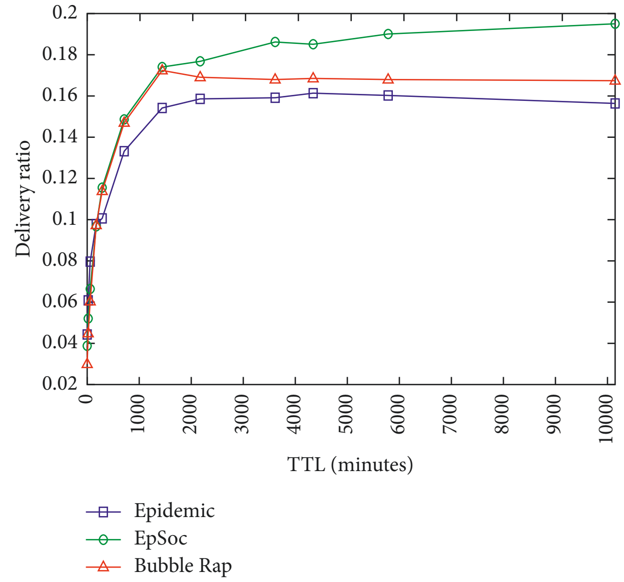

Figure 6: Delivery ratio versus TTL.

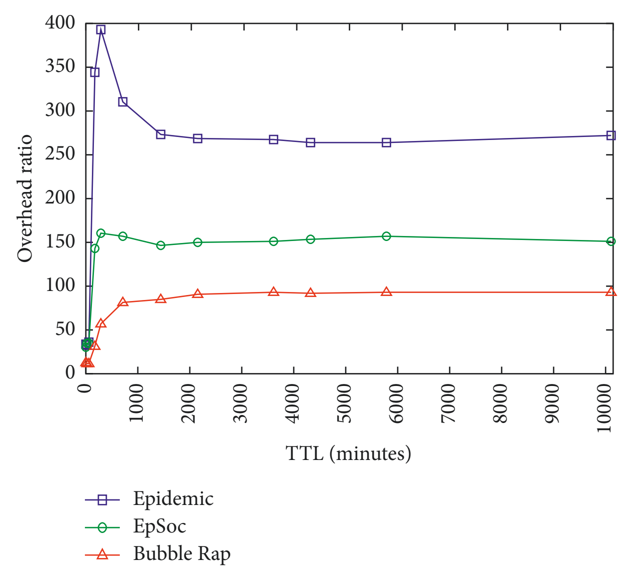

Figure 7: Overhead ratio versus TTL.

4.3.2. Varying Initial TTL. TTL determines the life of the message in the network. A high value of TTL gives high chances of the message delivered to the target destination and vice versa.

In Figure 6, the relation of delivery ratio with TTL is depicted. For lower TTL (10 m–3 h), the delivery ratio of Epidemic is slightly higher than that of Bubble Rap and EpSoc. The reason is that, for short TTL messages, exploiting social features will not be very effective due to quickly messages dropping. In addition, the higher replication occurred in Epidemic increases the number of delivered messages. When TTL is increased, Bubble Rap and EpSoc outperform Epidemic due to utilizing the social features. In high TTL scenarios (1.5 d–1 w), EpSoc outperforms Bubble Rap. This indicates an efficiency of EpSoc in its social feature selection.

Shortening the life of messages in the active nodes and blocking runout TTL messages from hitting again the active nodes cause an increment in the delivered messages and decrement in forwardings. Therefore, delivery ratio grows up.

Figure 7 compares the performance of the protocols with different values of TTL in terms of overhead ratio. When TTL is very low (10 m–1 h), Epidemic, EpSoc, and Bubble Rap achieve low overhead. The reason is that messages are dropped quickly. For high TTL values, Bubble Rap achieves the best and Epidemic the worst.

Our protocol EpSoc manages to decrease the overhead better than Epidemic. This is because EpSoc is a combination of the flooding-based forward strategy with social features.

From Figure 8, in terms of average latency, EpSoc appears to be outperforming others especially with high TTL

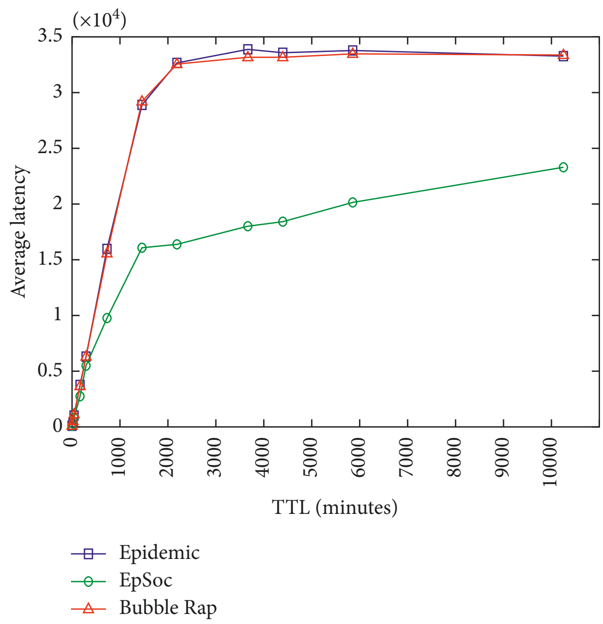

Figure 8: Average latency versus TTL.

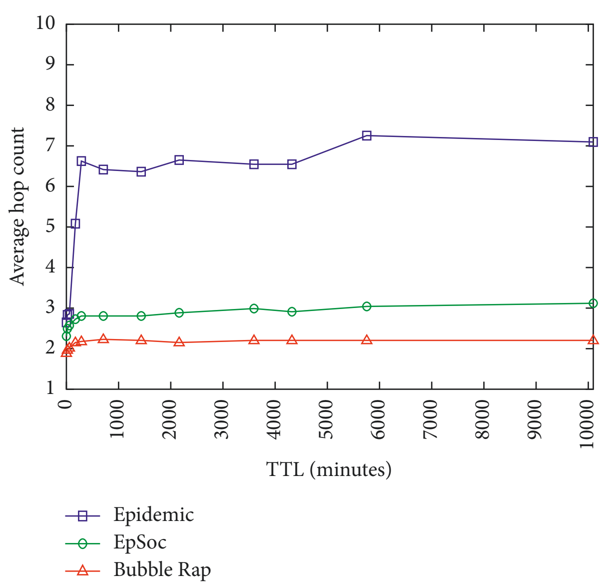

Figure 9: Average hop count versus TTL.

values (12 h–1 w). This is because our algorithm always enables the active node to carry messages with lower TTL.

From Figure 9, we observed that if TTL is very low (10 m–1 h), all routing protocols in the experiment have low average hop count. This is due to the low number of forwardings between nodes as message life exhausted quickly. Bubble Rap and EpSoc have almost stable performance when TTL is increased. Exploited social features in Bubble Rap and EpSoc and applying the blocking mechanism in EpSoc decrease the effect of changing the value of TTL on the number of traversed nodes to the destination. On the contrary, when the TTL is increased, the average hop count of Epidemic increases significantly because of the flooding-based forwarding strategy. For EpSoc, the average hop count is decreased significantly compared to Epidemic because of the social effect of active nodes.

5. Conclusion

In this paper, we investigate the flooding-based forwarding strategy, that is, Epidemic with social features to improve the routing performance in the opportunistic mobile social network (OMSN). Inspired by the advantages of Epidemic routing protocols in terms of delivery ratio and delivery delay and by exploiting the social activity of nodes, we formulated a flooding-based social-based routing protocol named as EpSoc. Simulation experiments using real data sets are conducted to evaluate our protocol performance. From the presented results, our approach increases the delivery ratio and decreases the delivery overhead, average latency, and average hop count as compared to the Epidemic protocol. As for benchmark social-based routing protocol performance (Bubble Rap), our protocol decreases the average latency significantly with a better delivery ratio in high buffer size and low TTL scenarios. Generally, we manage to exploit the advantage of Epidemic and Bubble Rap to improve the data dissemination in the OMSN.

Additional Points

Significance. Social features of a node can be utilized to have an effective role in the routing protocol in the OMSN network. This paper presents the routing protocol that exploits degree centrality to increase the delivery ratio and decrease the overhead and latency. Moreover, exploiting other social features such as similarity and community may lead to being more efficient routing protocol. Therefore, combining social features with other forwarding techniques such as the Epidemic-based strategy is significant to have an efficient forwarding strategy in the OMSN to support green technologies.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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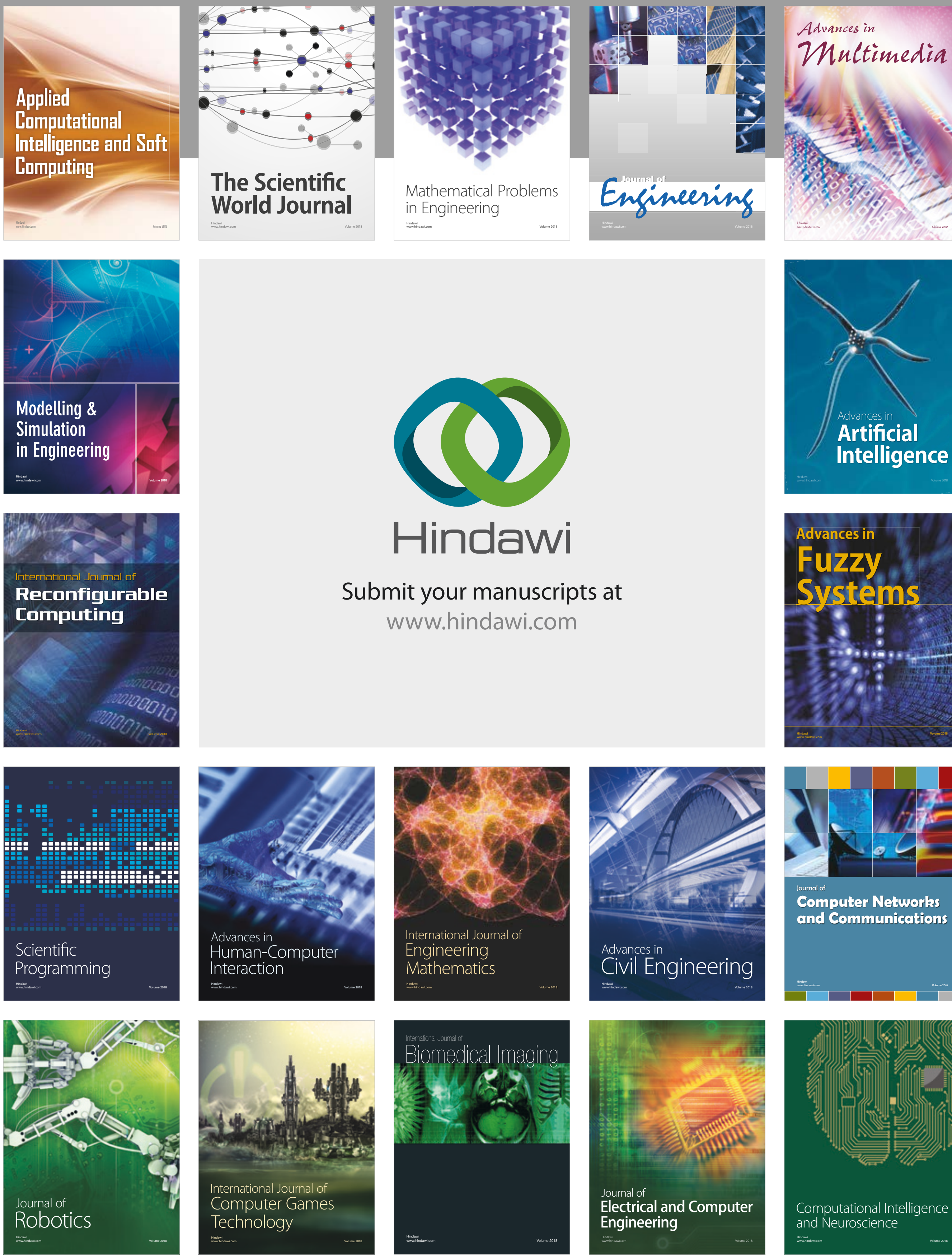
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