Directional-IPeR: Enhanced Direction and Interest Aware PeopleRank for Opportunistic Mobile Social Networks

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Abstract: Network infrastructures are being continuously challenged by virtue of increased demand, resource-hungry applications, and at times of crisis when people need to work from homes such as the current Covid-19 epidemic situation, where most of the countries applied partial or complete lockdown and most of the people worked from home. Opportunistic Mobile Social Networks (OMSN) prove to be a great candidate to support existing network infrastructures. However, OMSNs have copious challenges comprising frequent disconnections and long delays. In this research, we aim to enhance the performance of OMSNs including delivery ratio and delay. We build upon an interest-aware social forwarding algorithm, namely Interest Aware PeopleRank (IPeR) in two ways 1) By embracing directional forwarding (Directional-IPeR), and (2) By utilizing a combination of Directional forwarding and multi-hop forwarding (DMIPeR). Different interest distributions and users' densities are simulated using the Social-Aware Opportunistic Forwarding Simulator (SAROS). The results show that Directional-IPeR with a tolerance factor of 75% performed the best in terms of delay and delivery ratio compared to IPeR, and two other algorithms, namely MIPeR and DMIPeR.

1 INTRODUCTION

Network infrastructures are experiencing notable challenges (Vahdat & Becker, 2000), especially with increased demand, and at times of worldwide crises when people work from home, and infrastructures are stretched to their limits. Opportunistic Mobile Social Networks (***OMSNs***)**,** can provide excellent complimentary support to existing network infrastructures. OMSN is the combination of Opportunistic Network (***ON***) and ***MSN***. *ON* is Mobile Ad hoc Network (MANET) with frequent disconnections where there is no information about the network connection or the nodes' mobility patterns. To deliver the message to its destination, ON uses some nodes as intermediate carriers to host the message and forward it to other nodes until it reaches the destination. In ONs, the node forward or store-and-carry the message occurs at or takes place at every hop. Consequently, the delay between being out of range and back must be considered. Consequently, ON is also called Delay Tolerant Network or Disruption Tolerant Networks (DTN). Mobile Social Network (MSN) constitutes a Social Network (SN) that is based on the interaction of a group of people using their mobile devices. The interactions in MSNs establish relationships or links which can be physical contact, a shared interest, age, language, place, or any other relationships. It employs social advantages as well as the capabilities of smartphones like GPS, sensing features, and communication links. Thus, OMSNs are Ad hoc networks in which the nodes are in motion with recurring disconnections using mobile devices. (Rajpoot & Rajendra, 2015) (Sobin, Raychoudhury, Marfia, & Singla, 2016) (Pal, Saha, & S.Misra, 2017) (Hom, Good, & Yang, 2017) (Zhu, Xu, Shi, & Wang, 2013) (Vasilakos, Spyropoulos, & Zhang, 2016) (Wu & Wang, 2014) (Liu & Jing, 2012) (Sui, 2015).

There are many challenges however that face OMSNs including long delays and frequent disconnections. Consequently, the certainty of delivering a message to its destination is compromised (Li, Joshi, & Finin, 2010) (Moati, Otrok, Mourad, & Robert, 2013).

In this research, we contribute to enhancing the performance of some of the well-established algorithms used for OMSNs including, but notlimited to, enhancing delivery ratio and reducing delay. Our work builds upon Interest Aware

PeopleRank (IPeR), which was developed an interest and social aware algorithm that outperformed comparable algorithms (Al Ayyat, Harras, & Aly, 2013) and its multi-hop variant, Multiple Hops Interest Aware PeopleRank (MIPeR) (Shahin, Al Ayyat, & Aly, 2020). We worked on two major fronts (1) embracing direction as a guiding criterion in ranking nodes in support for content forwarding decision making based on IPeR, Direction and Interest Aware PeopleRank (Directional-IPeR), and (2) utilizing the combination of MIPeR and Directional-IPeR in ranking nodes in support for content forwarding decision making Directional Multiple Hops Interest Aware PeopleRank (DMIPeR). For Directional-IPeR, we utilize different values of what we call the tolerance factor to experiment with different ways of selecting forwarder nodes while keeping direction into consideration. The tolerance factor is a percentage, namely, 25%, 50%, and 75%. We multiply the IPeR value by one of these tolerance factors to come up with a new value which is less than IPeR value to constitute a threshold below which we cannot send the data to nodes whose IPeR value is less than this threshold. For instance, the algorithm Directional-IPeR-75 selects the next forwarders with a tolerance factor of 75% of the IPeR value of the current message holder. For each experiment, different interest distributions as well as different user densities are employed. Based on the results of the simulation runs, adding direction guidance to IPeR with a 75% tolerance factor performs the best in terms of delay and delivery ratio compared to IPeR, MIPeR, and DMIPeR.

Our contribution consists of (1) the addition of direction awareness to the IPeR algorithm with some preset tolerance factor improved both the delivery ratio and the number of reached interested forwarders. (2) Including 2 and 3 hops to Directional-IPeR-75 do not gain any improvement. (3) In high- density areas, Directional-IPeR performs better in all metrics compared to IPeR except in terms of delay. However, in less crowded environments, it reduces delays. Therefore, it can be employed in rural or disastrous areas, in which few people have internet access with low connectivity and spread over a big area. Furthermore, Directional-IPeR-75 outperforms the SocialCast algorithm in all metrics except for cost. For instance, Directional-IPeR-75 reduced delay to 200% of that incurred by SocialCast.

The remainder of this paper is organized as follows. We discuss the related work in Section 2. Section 3 illustrates the concept of integrating direction awareness with interest-aware PeopleRank (Directional-IPeR), Section 4 presents simulation settings. Section 5 elucidates the evaluation results of the new algorithms, followed by a conclusion in Section 6.

2 RELATED WORK

Many contributions were made to mitigate some of the challenges associated with OMSNs. Beyond Epidemic routing (Vahdat & Becker, 2000), other protocols use contact history (Jain, Chawla, Soares, & Rodrigues, 2016) (Spyropoulos, Psounis, & Raghavendra, 2005) (Abdelkader, Naik, Nayak, Goel, & Srivastava, 2016) (Spaho, Bylykbashi, Barolli, Kolici, & Lala, 2016). The Probabilistic Routing Protocol using the History of Encounters and Transitivity (PRoPHET) protocol (Pathak, Gondaliya, & Raja, 2017) (Denko, 2016) (Vasilakos, Spyropoulos, & Zhang, 2016), for instance, is grounded on using a set of probabilities, which are established on the history of past contact, to outline the successful delivery of the message to its destination. The Spray and Wait Protocol is considered the most appropriate store-carry-forward routing protocol. The goal of Spray and Wait is to reduce transmissions by reducing the total number of copies per message (Spyropoulos, Psounis, & Raghavendra, 2005) (Jain, Chawla, Soares, & Rodrigues, 2016). MaxProp gives more priority to the packets with the minimum number of hops by storing a vector that represents the likelihood to meet other nodes in the network (Spaho, Bylykbashi, Barolli, Kolici, & Lala, 2016).

Other protocols use centrality to represent the importance of nodes within the social network. Consequently, central nodes are better candidates to send messages to other nodes in the network (Zhu, Xu, Shi, & Wang, 2013) (Daly & Haahr, 2007). SimBet employs betweenness centrality using 1-hop and 2-hop neighbors and the local social similarity to choose the intermediary nodes for efficient message routing (Daly & Haahr, 2007).

Many protocols rely on constituted communities that can accelerate message delivery. In social networks, the members of one community tend to meet with a higher probability compared to other members who are not in the same community. (Cherif, Khan, Filali, Sharafeddine, & Dawy, 2017) (Palla, Derényi, Farkas, & Vicsek) (Hui, Crowcroft, & Yoneki, 2011) (Meng, et al., 2019) (Chang & Chen, 2014). Bubble RAP is a social network protocol, which is based on community and centrality metrics (Hui, Crowcroft, & Yoneki, 2011). First, a contact graph is employed to represent mobility traces. It relies on the number of contacts and the contact duration, where physical nodes are represented by nodes in the graph, the edges represent the contacts, and the weights on the edges represent the contact duration and frequency. To detect the communities of nodes in a social network, K-CLIQUE and Weighted Network Analysis (WNA) are applied. Other protocols rely on friendship to constituent communities. Friendship in OMSN is based on having a regular and longtime duration of contacts or have a shared interest (Wu & Chen, 2016) (Chen & Wu, 2016) (Perrig, Stankovic, & Wagner, 2004) (Dubois-Ferriere, Grossglauser, & Vetterli, 2003) (Bulut & Szymanski, 2012). For instance, Friendship-Based Routing Protocol (FBR) is based on community and friendship metrics. It can detect the direct and the indirect friendship between nodes based on three features, namely, regularity, frequency, and longevity of the contacts. Regularity indicates the variance of the inter-meeting time. Frequency indicates the average inter-meeting time. Longevity is the average duration time of the meeting sessions (Bulut & Szymanski, 2012).

Other protocols rely on location guidance (Barkhuus & Dey, 2003) (LeBrun, Chuah, Ghosa, & Zhang, 2005) (Kim, Choi, & Yang, 2015). Hotspots or Stop points are locations, in which people tend to gather. Forwarding a message in hotspots can guarantee it reaches a big number of nodes. Some other protocols rely on the direction (Dhurandher, Borah, Woungang, Bansal, & Gupta, 2018) (Jeon, Kim, Yoon, Lee, & Yang, 2014). People are moving around in different directions, speeds, and visit different places. Based on this fact, if a message is forwarded to nodes, which are traveling to different places where the source node cannot go, then the message has a good chance to reach its destination. An example is Direction Entropy Based Forwarding Scheme (DEFS), which utilizes the main direction and the direction entropy to predict the nodes' direction and to identify the nodes that have high mobility and consequently high probability of meeting the destination of a message (Jeon, Kim, Yoon, Lee, & Yang, 2014).

Using social aspects such as the user interest, gender, age, or language is used to define a social vector that defines a rank, which is employed to forward the messages in OMSNs such as PeopleRank (Mtibaa, May, & Ammar, 2012), and Interest Aware PeopleRank (IPeR) (Al Ayyat, Harras, & Aly, 2013). SocialCast is a publish-subscribe routing framework that utilizes metrics of social interaction such as, patterns of movements to predict the best nodes to forward a message. It used a mobility model based on a social network (Costa, Mascolo, Musolesi, & Picco, 2008).

One of the protocols that are based on contacts is the Two Hops Prediction Protocol**.** To consider two hop communication, initially, the source node must have the information about the probability of contact of each of its neighbors with the destination. When two nodes meet, they exchange their unordered list of node IDs which have a contact probability above a certain threshold. Then, each node checks whether it has any message that is destined to any of the neighbors of the nodes in the list of the encountered nodes. If a message is found, a copy of the message is sent to the encountered node. This is repeated until the message reaches the destination. This protocol performed efficiently compared to Epidemic, Random, and PRoPHET Protocols (Song & Kotz, 2016)

In this paper, we explored the combination of direction, interest, and social awareness (Directional-IPeR) with one hop and multiple hops prediction. Directional-IPeR with one hop improved the delivery ratio and the number of reached interested forwarders. Employing multiple hops to Directional-IPeR does not gain any enhancement and instead increased the cost. In crowded areas, Directional-IPeR performs better in all metrics compared to IPeR except for delay. However, it reduces delays in less crowded areas. Consequently, it fits in all environments.

3 INTEGRATING DIRECTION AWARENESS WITH INTEREST-AWARE PeopleRank

In this section, we introduce direction awareness to interest-aware social-based forwarding algorithms that recognize destination nodes by their interest profile. First, we use IPeR and its variation MIPeR as interest-aware social-based forwarding algorithms in OMSNs. We then introduce the Directional-IPeR algorithm which integrates direction awareness in IPeR.

IPeR is an interest-aware social forwarding algorithm (Al Ayyat, Harras, & Aly, 2013) that introduces interest awareness in ranking the mobile nodes besides the typical social ranking and activeness used in the social-based ranking PeopleRank algorithm (PeR) (Mtibaa, May, & Ammar, 2012). Each node carries a PeopleRank value, which ranks nodes as per their social popularity, the node has its interest vector in terms of the topivcs of interest not concerning the exchanged messages. When a message is going to be exchanged/forwarded to a node, the interest vector of the message is sent to the nearby nodes. Each node compares its interest vector with that of the message to come up with a Jaccard similarity (Bank & Cole, 2008) index value. To elaborate, when a group of nodes has a higher or equal interest and PeopleRank values than the current node, each member of this group receive a copy of the message. On the other hand, to make nodes other than the source and destination nodes participate in delivering a message; a copy of the message is directed to the nodes, which have an interest in its content. It is a sort of an incentive for these nodes to sacrifice part of their storage and power when participating in delivering a message to other nodes. IPeR reduces the delivery cost, and delay in comparison to that of Epidemic and PeopleRank algorithms (Al Ayyat, Harras, & Aly, 2013)

Routing tables can be evolved to enhance the forwarding mechanism in OMSNs to reduce network flooding (Takasuka, Hirai, & Takami, 2018). Intending to explore the effect of considering the number of contacts with the encountered nodes, MIPeR uses the IPeR value of the nodes and accumulates them by using such routing tables. Thus, the routing information includes the node's PeopleRank and degree of interest in the message content (IPeR). However, these values are updated based on the number of contacts with the encountered nodes, to compute the 2 or 3 hop routing (MIPeR) values. As per the simulation results published in earlier research (Shahin, Al Ayyat, & Aly, 2020), the 2Har-MIPeR algorithm performs better in terms of the number of reached interested forwarders and delay compared to IPeR. It even performed better than its 3 hop version. The denser the environment is, the more delivery ratio, the more reached interested forwarders, the less cost and less delay exerted by the algorithm.

3.1 Directional-IPeR

Directional-IPeR introduces direction awareness into the forwarding decision of the IPeR algorithm. The aim is to increase the chance that a copy of the message is sent to all four directions with certain ratios to increase the probability of reaching the destinations. With the inspiration of Direction Entropy Based Forwarding Scheme (DEFS) (Jeon, Kim, Yoon, Lee, & Yang, 2014) each node has its transmission range divided into 4 quarters namely R1, R2, R3, R4 with an angle of 90 degrees as illustrated in Figure 1. Each node stores its locations at the latest two-time slots. Then, it compares them to find the difference, which will map its direction of motion to one of the 5 states (S0, S1, …S4). Note that state S0 indicates that the node did not move.

In IPeR, when a group of nodes has IPeR values higher than or equal to that of the message holder node, they receive a copy of the message. They are illustrated in Figure 1 as rectangles. The Directional-IPeR algorithm examines the four main directions of the nodes in this group. If MH finds a direction to which no nodes are heading, it sends a copy of the message to other nodes that are heading in this direction but has an IPeR value greater than the tolerance factor. Such a case is illustrated in Figure 1 as the circle in R3. It sacrifices a percentage of The IPeR value threshold for selecting the forwarder nodes to be sure that all of the four main directions are covered. The goal is to increase the delivery ratio but with the consideration of the cost. The Directional-IPeR algorithm is illustrated in Algorithm 1.

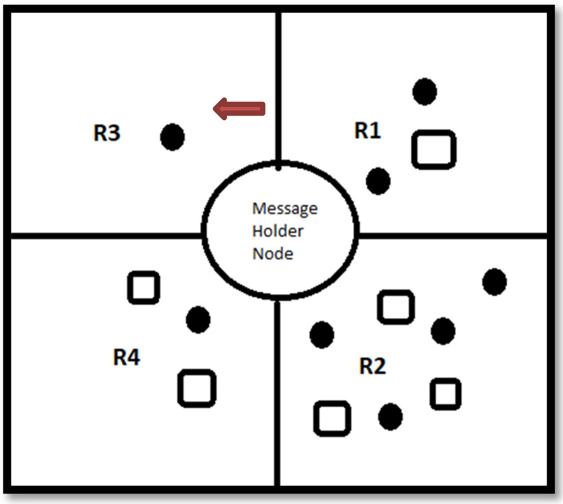


Figure 1: Forwarder node selection in the Directional-IPeR algorithm.

To simulate real-life scenarios, we should expect that some uninterested nodes may refuse to participate in the message delivery process as they have no interest in This message content. We tried this attitude in Directional-IPeR. Consequently, no message delivery that is taking place from those nodes.

Algorithm 1: Directional-IPeR.

```
Function Directional-IPeR (runs on message holder node)
Input:
  IPeRList ← all the nodes in contact with the message holder node and their IPeR value is >= to the message holder node's IPeR value
  ContactList ← all the nodes in contact with the current node and their IPeR value >= X% of message holder's IPeR value, and their IPeR value < the message holder node's IPeR value
Output:
  Directional_IPeRList
Declare lists s1, s2, s3, s4, Directional_IPeRList as lists of type node
Directional_IPeRList ← IPeRList
For each node N in Directional_IPeRList do
  nodeState ← requestState(N)
  map N to the corresponding state list
For each empty state SX
    While SX is empty
        For each node CN in ContactList do
            nodeState ← requestState(CN)
            if nodeState == SX
            map CN to SX
 add CN to Directional_IPeRList
```

3.2 DMIPeR: Hybrid Directional Multi Hops IPeR

Based on the best results of Directional-IPeR, MIPeR is merged with the best variation of Directional-IPeR. Therefore, two extra pieces of information are added to each node, namely, its contacts and its direction of motion. When two nodes meet, then specify that its value will be the MIPeR value, not the IPeR value. Then, a group of nodes is formulated. Each node in this group has their MIPeR value greater than the IPeR value of the message holder node. Based on that, if any direction is not covered by this group, other nodes which are expected to head to this direction get a copy of the message based on a predefined IPeR tolerance factor. DMIPeR algorithm is illustrated in Algorithm 2.

Algorithm 2: DMIPeR.

```
Function DMIeR (runs on message holder node)
Input
  IPeRList ← all the nodes in contact with the message holder node and their IPeR value is >= to the message holder node's IPeR value
  ContactList ← all the nodes in contact with the current node and their IPeR >= X% of message holder IPeR value, and their IPeR value< the message holder node's IPeR value
Output:
  DMIPeRList
 2HarIPeRList ← 2HopHarmonicMean(IPeRList) (Shahin, Al Ayyat, & Aly, 2020)
 DMIPeRList ← Directional-IPeR(2HarIPeRList, ContactList)
```

4 SIMULATION

In this section, we evaluate our proposed algorithms via simulation and validate our results using Self-similar Least Action Walk (SLAW) mobility models (Lee, Hong, K, Rhee, & Chong, 2012). We briefly describe our setup, and present a subset of our results.

4.1 Simulation Setup and Parameters

We used the SAROS simulator (Al Ayyat, Aly, & Harras, 2016) because it provides a wide variety of opportunistic forwarding algorithms and their related evaluation metrics. Besides, it correlates a diversity of interest distributions and social network integration associated with imported real traces. Besides, it generates random social profiles including interest for each user. To gain authentic results we used SAROS as it is the same simulator used to evaluate IPeR, which is the algorithm we are enhancing.

In our experiments, SAROS was adjusted to work over an area of 1000m x 1000m on extracted user traces from (SLAW) mobility model (Lee, Hong, K, Rhee, & Chong, 2012). SAROS incorporates social contexts and interests among people in small scale communities such as malls. Furthermore, the constructed friendship graph includes up to 20% of the available users in the friend list per user. To get authentic results, each experiment is run 20 times and the average is calculated. Each run delivers 2 messages in an hour. Every 20 runs are applied with different user densities and different interest distribution, namely; discrete uniform, normal and, two disjoint subgraphs. In the discrete uniform interest distribution, the users are spread equally between 11 categories with varying interest rates ranging from 0 to 1. Accordingly, the destination set establishes 18% of the nodes while the interested forwarders cover 36%. In the normal interest distribution, the destination set embraces 2% of the community, the interested forwarders set comprises 48%, while the remaining 50% are uninterested nodes. In the two disjoint subgraphs distribution of interest, which is a challenging environment, the destination set embraces 2% of the community and the remaining 98% are uninterested nodes. The most important simulation environment parameters are listed in Table 1.

Table 1: Simulation Environment Parameters.

Parameter	Value
No. of users	50, 100, and 200
No. of messages:	2
Set of Interests	10
Similarity interest distribution	Discrete uniform, discrete normal, and two disjoint subgraphs
Initial Battery Distribution	Full Battery Distribution
max user move	1.42m / 1 sec.
Simulation Duration	1 hour
Tolerance Factor of Directional-IPeR	Zero, 25%, 50% and 75%

4.2 Simulation Metrics

Since our goal is to evaluate the efficiency and effectiveness with which we can opportunistically reach users in OMSNs. We particularly use the following metrics: **delivery ratio,** the **ratio of contacted interested forwarders, delay, F-measure,** and **delivery cost**. The delivery ratio is the number of reached destination nodes to the total number of destination nodes that should receive the message. Delay is the average time consumed for a message to reach the destination node since it was sent from the source node. It is presented in the figures in a normalized form where the delay in minutes is divided by the simulation time (60 minutes). Delivery cost is the number of copies of the message. it is presented in the figures in a normalized form where the cost is divided by the max. the number of message replica that can be generated among the X number of users (e.g. 200 message replica by 200 users). F-measure is the harmonic mean of precision and recall. It is utilized to implement a type of penalty for reaching uninterested forwarders. Note that the targeted true set consists of the interested forwarder nodes in addition to the destination nodes, while the false set contains the uninterested nodes.

Each experiment is implemented using 3 different densities, which are 50, 100, and 200 users. Each user density is implemented with three different distributions of interests, which are uniform, normal, and two disjoint subgraphs.

5 RESULTS

In this section, we present the simulation results. First, we present Directional-IPeR. Then, the special case of Directional-IPeR, which is Directional-IPeR with random discard is demonstrated. It happens when some uninterested forwarders decide to discard the message and not to forward it to other nodes. Finally, Hybrid Directional Multi Hops IPeR (DMIPeR) is presented. It utilized 2 and 3 hops to Directional-IPeR.

5.1 Directional-IPeR

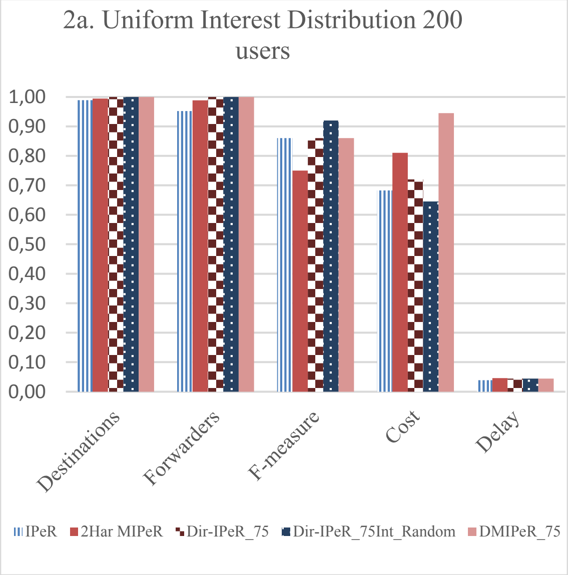
For all distributions of interest and users' densities, Directional-IPeR-75, which is based on including nodes with IPeR value not less than 75% of the message holder's IPeR value, is the best algorithm proposed for direction guidance in terms of F-measure and cost. *For uniform distribution*, it performs better than IPeR in terms of delivery ratio (up to 1% for 200-user experiments), reached interested forwarder nodes (up to 19% for 50-user experiments), and F-measure (up to 1% for 50 and 100 user experiments). Also, it reduces delays (up to 11% for 50 users). For the different densities of users, the denser the environment is the more delivery ratio, the more reached interested forwarders, and the less delay exerted by the algorithm as illustrated in Figure 2a. For example, if we have two environments. one environment encompasses 100 users while the other environment has 1000 users. Within the latter environment, more destination nodes, more interested forwarders, and fewer delays are achieved.

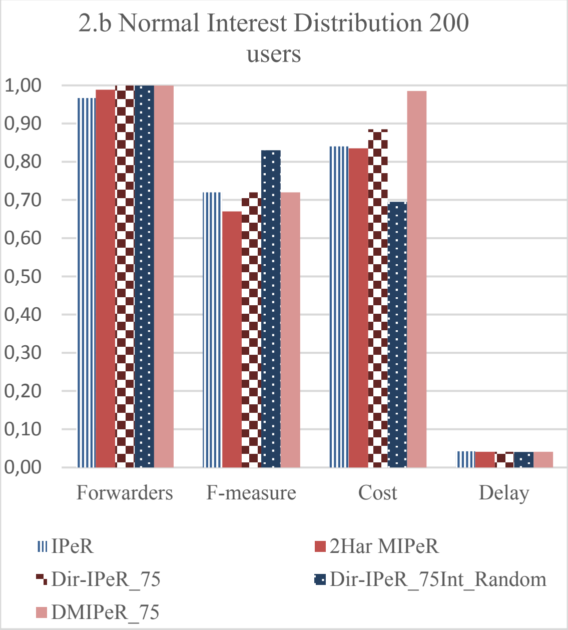
For the normal distribution, it performs better than IPeR in terms of reached interested forwarder nodes (up to 13% for 50 users), and delay (up to 27% for 50 users). For F-measure, it performs equally or better compared to IPeR. For the different user densities, the denser the environment is, the more reached interested forwarders, and the less delay exerted by the algorithm as illustrated in Figure 2b.

For the two disjoint subgraphs distribution, it performs better than IPeR terms of delay by 33% in low users' density and in terms of the delivery ratio by 1% in high users' density. Figure 2c indicates the performance in dense environments. In this such challenging environment, where there are no interested forwarders, Directional-IPeR-75 performed better than IPeR as it can approach more delivery ratio with a slight increase of delay in dense environments and perform equally in terms of delivery ratio with decreased delay in sparse environments. That is why it is not tested among the other two algorithms, Dir-IPeR_75Int_Random, and DMIPeR_75.

5.2 Directional-IPeR with Random Discard

Generally speaking, Directional-IPeR-75-random performed better in all metrics compared to IPeR. For uniform distribution, the enhanced F-measure (up to 8% for 50 users) and cost (up to 7% for 50 users). For the normal distribution, it enhanced F-measure (up to 18% for 100 users) and cost (up to 21% for 200 users). The denser the environment is, the more delivery ratio, the more number of reached interested forwarders, and the less delay as illustrated in Figures 2a, 2b, 2c, and 3.





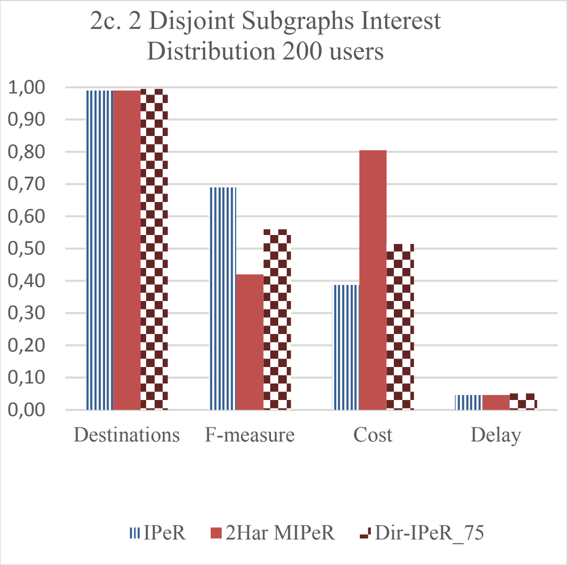


Figure 2: Performance of all algorithms within 200 users' density.

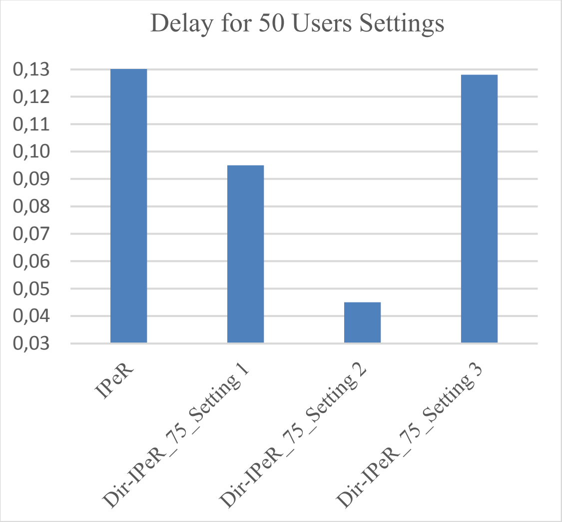


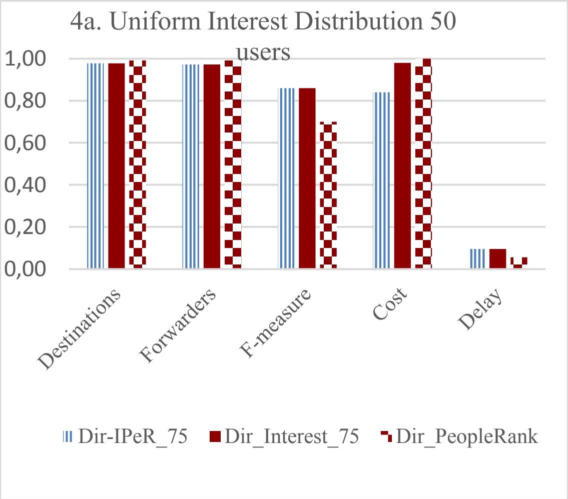
Figure 3: Delay for 50 users, *setting 1= Uniform Interest Distribution, setting 2 = Normal Interest Distribution and setting 3= 2 Disjoint Subgraphs Interest Distribution.

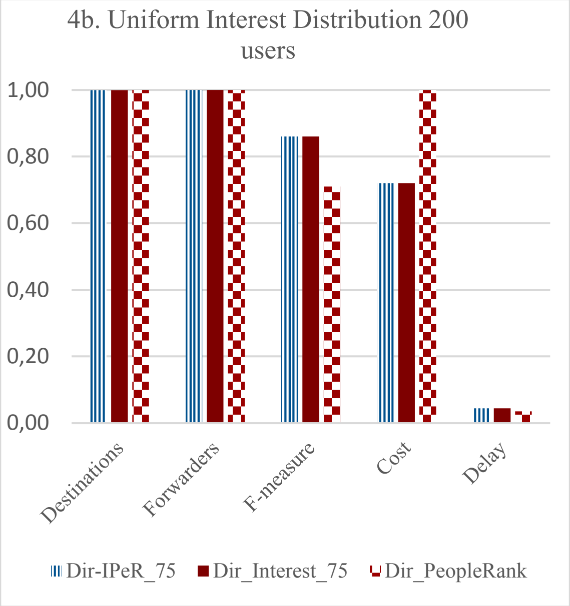
5.3 DMIPeR: Hybrid Directional Multi Hops IPeR

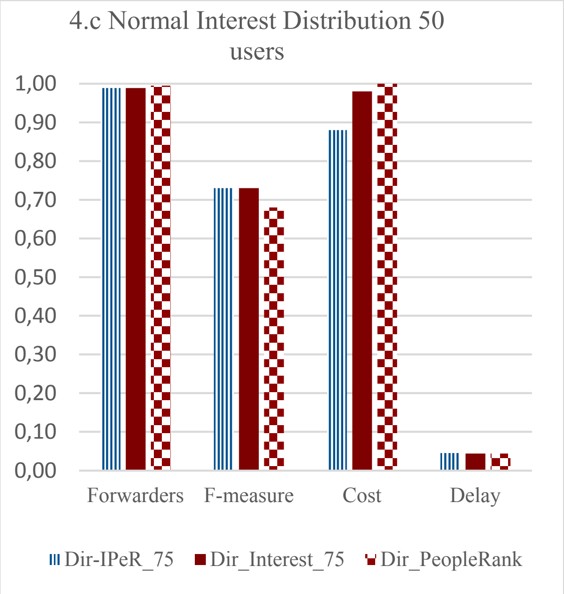
Directional-IPeR-75, which is the best algorithm for Directional-IPeR, performs equal to its corresponding DMIPeR in all metrics. However, it increases cost (up to 36% for 100 users' density in Uniform Interest Distribution, up to 13% for 50 users' density in Normal Interest Distribution, up to 61% for 200 users' density in 2 Disjoint Subgraphs Interest Distribution). Adding 2 hops did not gain any enhancement in all metrics as illustrated in Figure 2a and Figure 2b, 2c, and 3.

6 DISCUSSION AND COMPARISON

To authenticate the performance of Directional-IPeR-75, direction awareness is integrated into other algorithms that IPeR proved to be their superior. These algorithms include the Interest aware forwarding algorithm and PeopleRank algorithm. The resulted algorithms are Directional-Interest and Directional-PeopleRank, respectively.







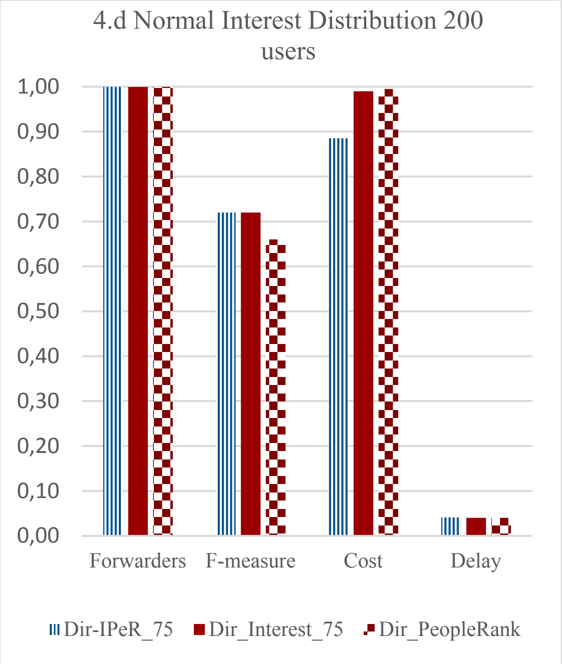


Figure 4: Comparing Directional-IPeR to Dir-Interest and Dir-PeopleRank.

Comparing Directional-IPeR-75 to Directional-Interest, they performed equally in all metrics, however, Directional-IPeR-75 performed better in terms of cost up to 17% in sparse density for uniform distribution as illustrated in Figures 4a and 4b. For the normal distribution, the enhancement in cost is up to 11%. In high users' density, they performed equally for uniform distribution but Directional-IPeR-75 enhanced cost by 12% for normal distribution as illustrated in Figures 4c and 4d.

Comparing Directional-IPeR-75 to Directional-PeopleRank, Directional-IPeR-75 performed better in terms of F-measure and cost up to 19% in low users' density for uniform distribution. For normal distribution, the enhancement in F-measure is up to 7% and the cost is up to 14%. In high users' density, Directional-IPeR enhanced F-measure by 17% and the cost is up to 39% for uniform distribution illustrated in Figures 4a and 4b. For the normal distribution, Directional-IPeR enhanced F-measure up to 8% and cost up to 13% illustrated in Figures 4c and 4d.

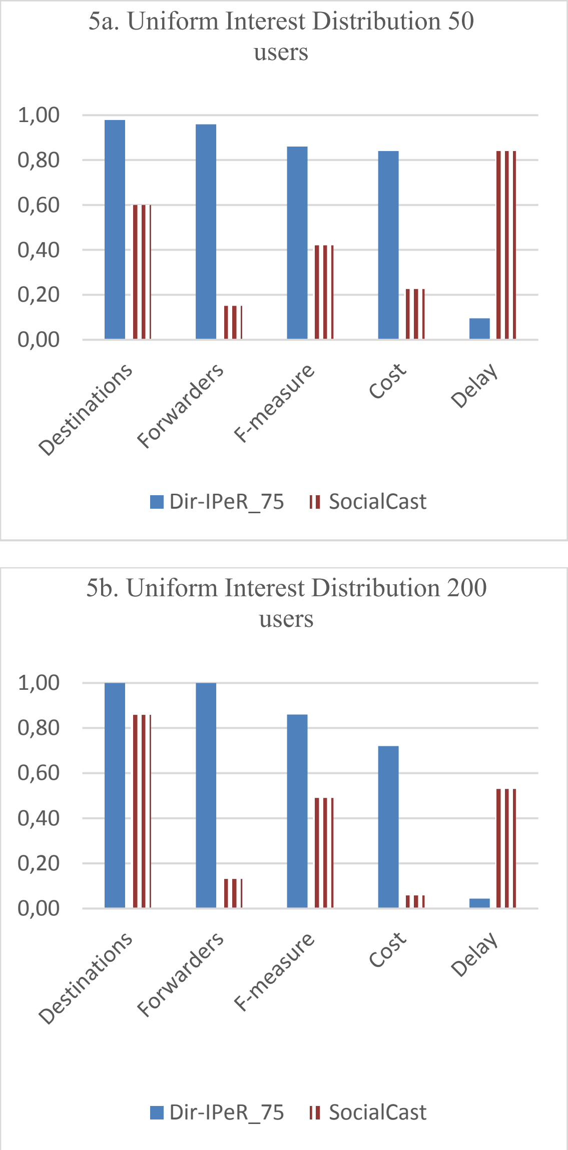


Figure 5: Comparing Directional-IPeR to SocialCast.

Further, Directional-IPeR-75 is compared to the SocialCast algorithm (Costa, Mascolo, Musolesi, & Picco, 2008) in a uniform distribution setting. Directional-IPeR-75 performed better in all metrics except cost in high and low density of users as illustrated in Figures 5a and 5b. Directional-IPeR-75 performs better than SocialCast in terms of delivery ratio (up to 39% for 50-user experiments), reached interested forwarder nodes (up to 87% for 200-user experiments), and F-measure (up to 51% for 50 user experiments). Also, it reduces delays (up to 1200% for 200 users).

7 CONCLUSION

In this paper, we have taken the first steps towards showing the impact of incorporating direction awareness with opportunistic forwarding algorithms such as IPeR, PeopleRank, and Interest aware forwarding algorithm. The proposed algorithms are Directional-IPeR, Directional-PeopleRank, and Directional-Interest, respectively. Furthermore, it outperforms the state of the art social-based opportunistic algorithm, SocialCast. Our simulation-based evaluation demonstrates the promising gain in delivery ratio, the number of reached interested forwarders, delay, and F-measure. Our contribution is defined as (1) Including direction awareness with tolerance up to 75% less than the IPeR value of the message holder (exemplified in the Directional-IPeR-75 version) improves delivery ratio and the number of reached interested forwarders. However, when some of the uninterested forwarders did not participate in messages delivery, which is a realistic behavior, the performance is enhanced and generally performed better in all metrics compared to IPeR. (2) Adding multiple hops to directional guided IPeR does not gain any enhancement. (3) Directional-IPeR-75 performs better in high densities in all metrics except delay. Even though, it enhances delay in sparse environments. Consequently, it can be utilized in rural or disastrous areas, in which few people have internet access with low connectivity and spread over a big area.

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REFRENCES

Abdelkader, T., Naik, K., Nayak, A., Goel, N., & Srivastava, V. (2016). A performance comparison of delay-tolerant network routing protocols. *IEEE Network, 30*(2), 46-53.

Al Ayyat, A., Aly, S., & Harras, K. (2019). On Integrating Space Syntax Metrics with Social-aware Opportunistic Forwarding. *IEEE Wireless Communications and Networking Conference (WCNC). I*, 1-7.

Al Ayyat, S., Aly, S., & Harras, K. (2016). SAROS: A social-aware opportunistic forwarding simulator. *IEEE Wireless Communications and Networking Conference*, 1-7.

Al Ayyat, S., Harras, K., & Aly, S. (2013). Interest aware peoplerank Towards effective social-based opportunistic advertising. *IEEE Wireless Communications and Networking Conference (WCNC), Shanghai*, 4428-4433.

Bank, J., & Cole, B. (2008). Calculating the jaccard similarity coefficient with map reduce for entity pairs in wikipedia. *Wikipedia Similarity Team*, 1-18.

Barkhuus, L., & Dey, A. (2003). Location-Based Services for Mobile Telephony: a Study of Users' Privacy Concerns. *Interact*, 702-712.

Bulut, E., & Szymanski, B. (2012). Exploiting friendship relations for efficient routing in mobile social networks. *IEEE Transactions on Parallel and Distributed Systems, 23*(12), 2254-2265.

Burgess, J., Gallagher, B., Jensen, D., & Levine, N. (2006). Max Prop: Routing for Vehicle-Based Disruption-tolerant Networks. *Proceedings IEEE INFOCOM, 25TH IEEE International Conference on Computer Communications*, (pp. 1-11).

Chang, J., & Chen, C. (2014). CROP: Community relevance-based opportunistic routing in delay tolerant networks. *EICE TRANSACTIONS on Communications, E97-B*(9), pp. 1875-1888. Retrieved from https://ir.nctu.edu.tw/bitstream/11536/25183/1/000342729800015.pdf

Chen, Z., & Wu, J. (2016). Applying a sensor energy supply communication scheme to big data opportunistic networks. *TIIS, 10*(5), 2029-2046.

Cherif, W., Khan, M., Filali, F., Sharafeddine, S., & Dawy, Z. (2017). P2p group formation enhancement for opportunistic networks with wi-fi direct. *IEEE Wireless Communications and Networking Conference (WCNC)*, 1-6.

Costa, P., Mascolo, C., Musolesi, M., & Picco, G. (2008). Socially-Aware Routing for Publish-Subscribe in. *IEEE Journal on selected areas in communications,, 26*(5), 748-760.

Daly, E., & Haahr, M. (2007). Social network analysis for routing in disconnected delay-tolerant manets. *Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing*, 32-40.

Deng, X., Chang, L., Tao, J., Pan, J., & Wang, J. (2013). Social profile-based multicast routing scheme for delay-tolerant networks. *IEEE International Conference on Communications (ICC)*, 1857-1861.

Denko, M. K. (Ed.). (2016). *Mobile Opportunistic Networks: Architectures, Protocols and Applications.* CRC Press.

Dhurandher, S., Borah, S., Woungang, I., Bansal, A., & Gupta, A. (2018). A location Prediction-based routing scheme for opportunistic networks in an IoT scenario. *Journal of Parallel and Distributed Computing, 118*, 369-378.

Dubois-Ferriere, H., Grossglauser, M., & Vetterli, M. (2003). Age matters: efficient route discovery in mobile ad hoc networks using encounter ages. *Proceedings of the 4th ACM international symposium on Mobile ad hoc networking & computing* , 257-266.

Gondaliya, N., Kathiriya, D., & Shah, M. (2016). Contact frequency and contact duration based relay selection approach inside the local community in social delay tolerant network. *Proceedings of 3rd International Conference on Advanced Computing, Networking and Informatics (pp.). Springer, .*, 609-617.

Guo, B., Zhang, D., Yu, Z., Zhou, X., & Zhou, Z. (2012). Enhancing spontaneous interaction in opportunistic mobile social networks. *Communications in Mobile Computing, 1*(1), 1-6.

Hom, J., Good, L., & Yang, S. (2017, January). A survey of social-based routing protocols in delay tolerant networks. *Computing, Networking and Communications (ICNC)*, (pp. 788-792).

Hossen, S., & Rahim, M. (2016). Impact of mobile nodes for few mobility models on delay-tolerant network routing protocols. *International Conference on Networking Systems and Security (NSysS)*, 1-6.

Hu, X., Chu, T., Leung, V. C., Ngai, E. C., Kruchten, P., & C.Chan, H. (2015). A survey on mobile social networks: Applications, platforms, system architectures, and future research directions. *IEEE Communications Surveys & Tutorials, 17*(3), 1557-1558.

Hui, P., Crowcroft, J., & Yoneki, E. (2011). BUBBLE Rap: Social-based Forwarding in Delay Tolerant Networks. *IEEE Transactions on Mobile Computing, 10*(11), 1576-1589.

Jain, S., Chawla, M., Soares, V. N., & Rodrigues, J. J. (2016). Enhanced fuzzy logic-based spray and wait routing protocol for delay tolerant networks. . *International Journal of Communication Systems, 29*(12), 1820-1843.

Jeon, M., Kim, S. K., Yoon, J. H., Lee, J., & Yang, S. B. (2014). A direction entropy-based forwarding scheme in an opportunistic network. *Journal of Computing Science and Engineering, 8*(9), 173-179.

Kawecki, M., & Schoeneich, R. O. (2016). Mobility-based routing algorithm in delay tolerant networks. *EURASIP Journal on Wireless Communications and Networking*, 81-90.

Kim, S. -K., Choi, J. -H., & Yang, S. B. (2015). Hotspot: Location-based Forwarding Scheme in an Opportunistic Network. *Adhoc & Sensor Wireless Networks*(26).

LeBrun, J., Chuah, C., Ghosa, l. D., & Zhang, M. (2005). Knowledge-based opportunistic forwarding in vehicular wireless ad hoc networks. *IEEE 61st Vehicular Technology Conference*, 2289-2293.

Lee, K., Hong, S., K, S. J., Rhee, I., & Chong, S. (2012). SLAW: Self-Similar Least-Action Human Walk. *IEEE/ACM Transactions on Networking, 20*, 515-529.

Li, W., Joshi, A., & Finin, T. (2010). Coping with node misbehaviors in ad hoc networks: A multi-dimensional trust management approach. *in 2010 Eleventh International Conference on Mobile Data Management*, 85–94.

Liu, L., & Jing, Y. (2012). A Survey on Social-Based Routing and Forwarding Protocol in Opportunistic Networks. *Computer and Information Technology (CIT), IEEE 12th International Conference*.

Meng, X., Xu, G., Guo, T., Yang, Y., Shen, W., & Zhao, K. (2019). A novel routing method for social delay-tolerant networks. *Tsinghua Science and Technology, 24*(1), 44-51.

Moati, N., Otrok, H., Mourad, A., & Robert, J.-M. (2013). Reputation-based cooperative detection model of selfish nodes in cluster-based qos-olsr protocol. *Wireless Personal Communications, 75*(3), 1747–1768.

Mtibaa, A., May, M., & Ammar, M. (2012). Social forwarding in mobile opportunistic networks: A case of peoplerank. In *Handbook of Optimization in Complex Networks* (pp. 387-425). New York, NY: Springer.

Pal, S., Saha, B. K., & S.Misra. (2017). Game Theoretic Analysis of Cooperative Message Forwarding in Opportunistic Mobile Networks. *IEEE transactions on cybernetics, 47*(12), 4463-4474.

Palla, G., Derényi, I., Farkas, I., & Vicsek, T. (n.d.). Uncovering the overlapping community structure of complex networks in nature and society. *Nature, 435*(7043), 814-824.

Pathak, S., Gondaliya, N., & Raja, N. (2017). A survey on PRoPHET based routing protocol in delay tolerant network. *Emerging Trends & Innovation in ICT (ICEI), 2017 International Conference*, (pp. 110-115).

Perrig, A., Stankovic, J., & Wagner, D. (2004). Security in wireless sensor networks. 53-57.

Rajpoot, N., & Rajendra, S. K. (2015). An improved PRoPHET routing protocol for underwater communication. *In Communication Networks (ICCN)*, 27-32.

Shahin, Y. S., Al Ayyat, S. A., & Aly, S. G. (2020). *MIPeR: Enhanced Multiple Hops Interest Aware PeopleRank for Opportunistic Mobile Social Networks.* American University in Cairo, Computer Science and Engineering, Cairo.

Sobin, C., Raychoudhury, V., Marfia, G., & Singla, A. (2016). A survey of routing and data dissemination in delay tolerant networks. *Journal of Network and Computer Applications*(67), 128-146.

Song, L., & Kotz, D. F. (2016). Routing in Mobile Opportunistic Networks. . *Mobile Opportunistic Networks: Architectures, Protocols and Applications*(1).

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. *19th International Conference on Network-Based Information Systems (NBiS).*

Spyropoulos, T., Psounis, K., & Raghavendra, C. S. (2005). Spray and Wait: an efficient routing scheme for intermittently connected mobile networks. *Proceedings of ACM SIGCOMM 2005 Workshop on Delay Tolerant Networking and Related Networks (WDTN-2005)*, (pp. 252-259). Philadelphia.

Sui, Z. (2015). The Research of the Route Protocols in Opportunistic Network. *Computational Intelligence and Communication Networks (CICN)*, 192-196.

Takasuka, H., Hirai, K., & Takami, K. (2018). Development of a Social DTN for Message Communication between SNS Group Members. *Future Internet, 10*(4), 32.

Vahdat, A., & Becker, D. (2000). *Epidemic routing for partially connected ad hoc networks.* Technical report CS-200006, Duke University.

Vasilakos, A., Spyropoulos, T., & Zhang, Y. (2016). *Delay tolerant networks: Protocols and applications.* CRC press.

Vastardis, N., & Yang, K. (2013). Mobile social networks: Architectures, social properties, and key research challenges. *IEEE Communications Surveys & Tutorials 15*(3), 1355-1371.

Wu, J., & Chen, Z. (2016). Data decision and transmission based on mobile data health records on sensor devices in wireless networks. *Wireless Personal Communications, 90*(4), 2073-2087.

Wu, J., & Wang, Y. (Eds.). (2014). *Opportunistic Mobile Social Networks.* CRC Press.

Zhu, Y., Xu, B., Shi, X., & Wang, Y. (2013). A survey of social-based routing in delay tolerant networks: Positive and negative social effects. *IEEE Communications Surveys & Tutorials, 15*(1), 387-401.