SocialRouting: The social-based routing algorithm for Delay Tolerant Networks

Radosław O. Schoeneich, Rafał Surgiewicz

Abstract—**Delay and Disruptive Tolerant Networks (DTN) are relatively a new networking concept that could provide a robust communication in wide range of implementations from the space to battlefield or other military usage. However in such dynamic networks, which could be considered as a set of intermittently connected nodes, message forwarding strategy is a key issue. Existing routing solutions concentrate mainly on two major routing families flooding and knowledge based algorithms. This paper presents SocialRouting - the social-based routing algorithm designed for DTN. The use of the social properties of wireless mobile nodes is the novel way of message routing that is based on message ferrying between separated parts of the network. Proposed idea has been extensively tested using simulation tools. The simulations were made based on especially designed for measurements in DTN scenarios and compared with popular solutions.**

Keywords—**Routing Protocols, MANET, DTN.**

I. INTRODUCTION

NOWADAYS Delay and Disruptive Tolerant Networks (DTN) [1] are dynamically explored. The ad-hoc DTN is a collaboration of nodes which are connected via wireless links in a spontaneous manner. The DTN is characterized by a changeable structure of the network. It also has another property, of highest importance: due to permanent network partitions, the path between message source and destination usually does not exists. The communication in the DTN network is done by ferrying messages between separate sub-networks, using mobility of nodes. This style of functioning is known as a store-and-forward paradigm. The nodes which are storing and moving messages are called message ferries or mules.

Those mechanisms, which are relatively simple and well known to the old-fashioned human environment, such as post or courier services, cannot be easily implemented in an environment of small and mobile wireless networks. Although the technology progress is very fast, the communication and nodes storing capability are still an important problem to solve. Therefore, the proper routing algorithm is fundamental in the DTN network creation as it saves restricted node resources.

Due to acceptable disruptions in the structure of the network, the DTN may be used in many possible applications. It can be applied in: emergency and rescue scenarios, where traditional communication infrastructure is unserviceable e.g. in earthquake, or in hardly-accessible terrains, such as railway and metro tunnels. The small size of the node makes it possible to be carried by e.g. rescuers.

R. Schoeneich and R. Surgiewicz is with the Institute of Telecommunications, Warsaw University of Technology, Warsaw, Poland, e-mail: rschoeneich@tele.pw.edu.pl

The major contribution of this paper is the algorithm for routing messages in Delay and Disruptive Tolerant Networks using social properties of wireless nodes.

II. RELATED WORK

Routing organisation in ad-hoc wireless network is a not a trivial issue. It is specially difficult in wireless networks with high mobility nodes, where packet routes should be dynamically adapted to the current network topology. There are many different routing protocols in traditional ad-hoc networks. However, two major classes could be distinguished: proactive routing protocols and reactive ones. While the former consist of solutions which exchange routing information prior to message routing need, the latter trigger the routing discovery process when there is a need for routing. Due to disruptions the classical ad hoc routing protocols are not applicable for DTN, because of relaying on a complete end-to-end route from the source to the destination.

The goal of DTN routing solution is mainly to maximize the message delivering probability within the minimal time. Each node operates both as the receiver and transmitter, buffering and replicating the packet specified times and forwarding it to encounters. Clear advantage of this solutions is their robustness to quick network topology changes, significantly increasing the delivery ratio. Moreover, it is assured that the delivered packet travelled the shortest path. On the other hand, the concept of packed replication and forwarding messages to high number of nodes has many disadvantages. First and the most striking one is the fact that with the high number of packet copies along with the number of nodes a very high redundancy in the network occurs. Replicated copies are both network bandwidth and resource consuming. For the mobile nodes it could be simply concluded as not acceptable since they have limited hardware resources. Moreover, any demanding computations lead to impact on battery life.

The Direct Contact [2] routing scheme is not a typical algorithm. In this case only one message is transmitted in the network, which is basically kept by the Source node until it contacts with Destination. It does not require any further information about the network topology. However, in order to deliver the packet, a direct contact between source and destination is necessary. Therefore, if there is no contact, the message cannot be delivered.

Two-Hop-Relay routing [3] could be another solution as an extension to Direct Contact . It defines message forwarding scheme as following: If source node has a message to send, it is being transmitted to first N nodes that source comes

in contact with. Next, the nodes which received copy of the message hold it until they meet the destination node.

Epidemic Routing [4] is an representative of the flooding routing class algorithm is. It uses a concept of flooding the network with message replicas in the same way as widely spreading biological infection resulting in an epidemic. Source node replicate the message unlimited number of time and it transmits it to all encountered nodes. It is a much more robust solution, as compared to two algorithms described previously, because of its high redundancy. It also guarantees that when a message is received by the destination it is assured that the packet has been propagated to the most optimal path. On the other hand, the high number of extra message replicas eliminates it for usage in extensive networks.

SprayAndWait routing is the last example of solution of this family that we would like to present as one of the most effective packet forwarding strategy for DTN [5]. In this case the aim was to design a reliable routing scheme of high message delivery probability while not very resource consuming. In SprayAndWait a limited upper bound on the number of message replicas in the network is always defined. The relative algorithm could be divided into two different phases: Spray phase and Wait phase. In Spray phase message copies are being forwarded to encountered nodes. In Wait phase the algorithm forces a node to keep the received copy until destination node is encountered. There are two version differing in the definition of spraying message replicas: vanilla and binary.

The second group of solutions is based on knowledge of social characteristics. Many of the DTN applications, such as vehicular networks [6] and [7], mobile social networks [8], [9], [10], [11], [12], and disease epidemic spread monitoring, the most of mobile devices are carried by humans. Therefore, their behaviours, that are frequently schematic, are described by social models and helps in better forwarding decision of the new group of the DTN social-based routing. Social behaviours of mobile nodes are usually long-term characteristics and are less unstable than the node mobility. Basing on this observation, several social-based routing methods [13], [14], [15], [16], [17], [18] have been proposed. Exploiting various social characteristics, like community and centrality, the routing performance can be improved.

The human behaviour has also another characteristic that can be used in DTN routing, i.e. egoistic behaviour. An individual attempts to maximize his own utility while conserving own limited resources. Although the DTN routing is an cooperative activity, the routing operation can be critically impaired by egoistic behaviours. This observation serves as the basis for several social-based DTN routing protocols [19], [20], [21], [22], [23], [24], where users egoistic behaviours were taken into consideration by punishing nodes and/or stimulating their cooperation. The detailed survey of social-based DTN routing protocols can be found in works [25] and [26].

In conclusion, there are three categories of routing algorithms: message-ferry-based, opportunity-based, and prediction-based. In message-ferry-based methods extra mo-

bile nodes are employed, such as ferries for messages. Controlling of these nodes needs a extra cost. In opportunity-based schemes nodes forward messages randomly, but with no guarantees of success. The third one is based on the knowledge on nodes behaviour and, frequently, on its prediction. Our solution takes advantages of this social relations, what will be described in the next section.

III. SOCIALROUTING: SOCIAL-BASED ROUTING FOR DTN

There is a growing interest in wireless technologies designed for portable devices. They are differing in range, bandwidth and power consumption. They range from the one that provide high bit rate as Ultra Wide Band (UWB) [27] to Low Rate technologies, optimized in term of minimal power consumption. Concepts that use a group of low range devices to build an ad-hoc mesh network are very interesting and promising for further research. Messages are exchanged directly between nodes in the network. In case when no direct connection to destination occurs, the neighbour nodes are used to route the packets. This solution has a lot of advantages. Firstly, there is no preset network topology, secondly, the network is being created ad-hoc by the nodes, so there is no need to build any radio infrastructure. This feature is not only financially profitable, but also extremely useful in every situation where there is no possibility or not enough time to built any type of radio network. Examples could be emergency situations, such as: areas affected by disaster like flood, earthquake, fire etc. where emergency services or military have to be able to communicate almost immediately after the incident to save life. Other example could be military operations in different areas, such as wilderness where there is no possibility to build anything, or city at war where existing radio infrastructure is down and s an urgent need to be able to exchange operational messages occurs.

The DTN is obviously the best choice in the above-mentioned cases. The usage of the Delay Tolerant Networks could solve the majority of the problems connected to spatial transmission or even to the temporary lack of transmission possibility - store and forward mechanisms. For such networks a robust routing algorithm is the key to provide reliable communication.

A. General Description

As described in the previous selection, the choice of the routing algorithm is a compromise between the reliability, the delivery message time and the redundancy ratio in the network. Because of the lack of the universal solution which could be used in DTN networks, we would like to present our proposal, i.e. the Social Routing algorithm.

The Social Routing is aimed to provide reliable communication in DTN wireless ad-hoc mesh network created by various low range devices - personal devices. We have analyzed human behaviour and we have found out that even nowadays ordinary man carries several electronic devices that could be a part of the network e.g. notebooks, smart phones, e-book readers,
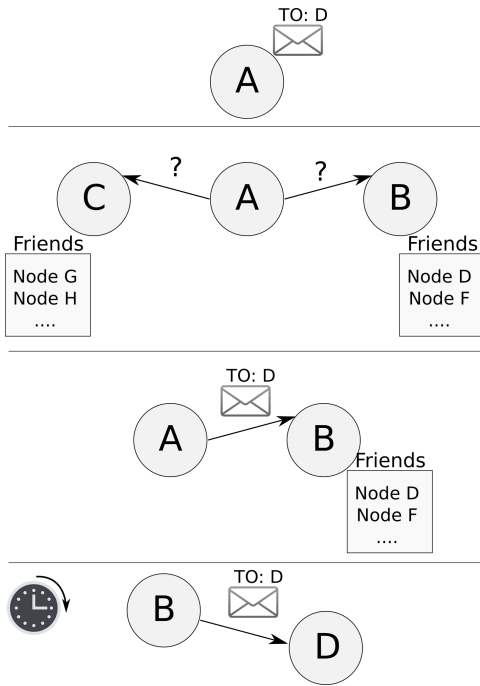
Fig. 1. Message forward using the knowledge about node social relationships.

Fig. 2. Maintenance operations performed to keep social relations up-to-date.

multimedia players etc. Basing on our observations, people carry devices that could be a part of a network, such as notebooks and smart phones.

Because of the fact that this equipment is usually an integral part of its owner we can draw a conclusion that the network node mobility and availability is conditioned by the behaviour of the user. As we all live in a society or constitute groups, a set of persons with which he or she has a relationship can be defined.

In this case relationship is defined in terms of periodical meeting and establishing contact with some frequency, e.g. a group of people travelling to the office on the same bus every day. They could hardly know each other, but they meet almost every day. If we then take a closer look on these behaviours and relationships, we can conclude that this information is very useful for routing organization [28].

The situation in which node A sends a message to destination node D is presented in Figure 1. Node A has no connectivity with D, however A can communicate with B. B is a friend of D and he or she communicates with him frequently. In this case, A should forward message to C. C will later deliver it to destination D. In this simple example we have shown that the usage of social node behaviour is vital to construct a distributed routing algorithm for this DTN network.

B. SocialRouting algorithm

1) Social properties: As described previously the Social - Routing algorithm uses knowledge about social behaviour of the node to ensure reliable message exchange. When designing we assumed that relationships of each node with others vary in time. However we decided to distinguish three types of
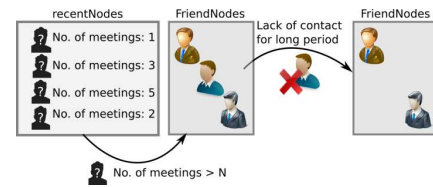
them: (a) Neighbours - list of nodes that one is with contact. (b) RecentNodes - everyone met during some time period (c) FriendNodes - nodes that are in some regular periodic contact. Groups reflect the social relationships for one node. In a network with high mobility nodes it is crucial to keep Neighbour list up to date to ensure that particular node is able to forward the message to nodes within current radio range. RecentNodes list stores information about all encountered nodes lately. Each time a node is met the table is updated with the exact time stamp. Also the table contains an information about number of occurred contact with each node. If encountered node was ever met then the meeting

counter is incremented. As it was described before from the frequency of contacts occurred between two nodes we assume that there is a social relationship between them. In SocialRouting we introduced a friendship determinant numeric parameter. If the value of meeting counter for the node is greater than the determinant threshold the node is marked as a friend and its record is saved into FriendNodes table. For each node FriendNodes table collects information about all nodes that are in a social relationship. For clear understanding we presented this actions in Algorithm 1 section. As in the real world some relationships expire and due to different reasons contacts with two nodes doesn't occur anymore. SocialRouting algorithm also implements a watchdog mechanism that observes frequency of friend nodes contacts. If the timeout timer is exceed and there was no meeting, previously friend node is removed from FriendNodes list. Overview of action performed by the mechanism responsible for keeping social node properties is illustrated in the Figure 2

2) SocialRouting metric: Routing metric is usually a number value used by routing algorithm to evaluate and find the best path to forward packets. In DTNs usually it is not possible to determine an end-to-end route e.g. links are only partially available.

```
Algorithm 1 Encountering node A
Neighbours:add(A; currentTime)
if A is in FriendNodes then
    FriendNodes(A):lastSeen   currentTime
    FriendNodes(A):updateSocialInfo()
else
    if A is in recentNodes then
        recentNodes(A):lastSeen    currentTime
        recentNodes(A):Counter + +
        if recentNodes(A):Counter> Determ.then
            FriendNodes:add(A)
            recentNodes:remove(A)
```
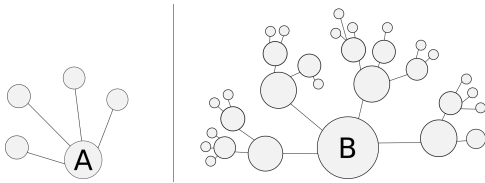
Fig. 3. The comparison between socially important B and less active node A.

```
      end if
   end if
end if
```

SocialRouting metric is called SocialRank and it is aimed to find the most useful node to be a message carrier. These nodes known also as a "message mules" should have a extensive network of social relations so they not only should have high number of friend nodes but also friend should be acquaintanced with some nodes. In the Figure 3 we present a comparison between node A - not very a active socially node with B - great candidate to be a message carrier node.

As we focused on designing the algorithm which reflects the social behaviour the rank should reflect it. It is calculated in not trivial way - it takes into account two main aspects: number of friend nodes and the SocialRank of this friend nodes:

$$SR = (NoFNodes * FWght) + (SRkFNod * FRankWght) \tag{1}$$

where FWght, FRankWght are the variable weight factors. A Social Rank of Friend Nodes (SRkFNod) represents an average SocialRank of the FriendNodes.

3) SocialRouting message forwarding: SocialRouting was designed to maximize the packet delivery probability. It does not only use the message multiplication based approach but combines it with the social node relationships knowledge to improve routing in the network. The algorithm operations could be divided into three stages: Spray, SocialSpray and Wait. In the Spray phase for each message there are two counters defined: Copies and SecondCopies which limit the total number of message copies in the network. Both are flexible parameters and could be adjusted adequately to current network environment. First counter: the Copies acts similar to the L counter described previously in vanilla SprayAndWait algorithm. Source forwards limited number of message copies to encountered nodes, each sent copy decrements the counter by one, until Copies = 1. Then node goes to SocialSpray phase when it can still distribute message replicas but only if certain conditions are satisfied. The packet will forwarded if encountered node: (a) has Destination in its FriendNodes list (b) has higher SocialRank then current node.

On receiving node when message copy is successfully transmitted the Copies counter is by default set to Copies = 1 to limit too much redundancy but SecondCopies is reset. This was designed also to shorten the delivery time: further copies are forwarded only to nodes that have a social relationship with the Destination and have high SocialRank, which means that they are important nodes in the network. If both Copies and SecondCopies counters are equal to 1, node switches to Wait phase. The message is only directly delivered to destination. Message forwarding algorithm pseudo-code is presented in the Algorithm 2.

```
Algorithm 2 Message forwarding

if  Copies > 1 then
   SendMessageCopy(A)
   Copies = Copies - 1
else
   if  SecondCopies > 1 and
   SocialRank > me:SocialRank and
   isF riendOf(D) then
      SendMessageCopy(A)
      SecondCopies = SecondCopies - 1
   end if
end if
```

IV. SIMULATIONS

There are many network simulators available on the market. However the is only a few which supports the disruptive networking model and implements mechanisms supporting events connected to node mobility in DTN network. An interesting alternative for well-known products is The ONE - The Opportunistic Network Environment simulator [29]. The tool delivers a simulation environment capable of simulating DTN nodes behaviour using different mobility models close to real-world examples such as WorkingDayMovement [30]. In the project the most important feature was that using The ONE we were able to simulate and analyze routing messages between nodes with various DTN routing algorithms. Also as an open-source project it is possible to expand the existing range of routing algorithms. For simulation and benchmarking we created a SocialRouting routing module which was then compiled with The ONE source files.

A. Simulation scenario

With the ONE it is possible to customize the simulation environment with its all properties. When defining simulated case we aimed to adjust it the way it would be close to the real word case. Since SocialRouting uses knowledge about the social relations of the node to show its proper behaviour we need to prepare a simulation scenario where this relations can appear and maintain. Perfect and unfortunately not feasible would be to reproduce 1:1 the nodes daily routines in the simulated word.

Our simulated scenario maps the city area (part of Helsinki, Finland) where we placed nodes with different mobility movements. To properly capture city live we set up four groups of nodes with different habits and movements. First group consist nodes representing people with the working day routines: in the morning they go to their office using car or public transport, then spends 8 hours in the office producing small movements within office area to finally directly come

TABLE I
SIMULATION PARAMETERS

Parameter	Values	Parameter	Values
Number of nodes	400	Copies	10
Number of groups	4	SecondCopies	5
Simulations time	1h-2weeks	FriendshipDet.	5
TTL	3600s	TimetoExp.	420
Routing type	Social,ER,SW	FFactor	0,4

back home or make some shopping before arriving home. This way by adjusting WorkingDayMovement model we were able to imitate the majority of city population. As in the regular city there are also individuals which movements are unpredictable we decided to add also a small amount of the nodes following the ShortestPathMapBasedMovement. It uses Dijkstra's algorithm to find shortest paths between random nodes and Points Of Interest which could be shopping, parks, cafes etc. Both office workers and pedestrians are assumed to have smart phone or similar device with Bluetooth with 512kbit/s bit rate radio interface embedded with 10 meter range. A reasonable storage buffer for messages of this mobile devices we estimated up to 50MB. As in every city there is a public transport also in the scenario we placed buses and trams and equipped them also with wireless interface with slightly broader radio range 25m and capacious flash storage with 100MB for forwarding messages.

B. Simulation parameters

SocialRouting algorithm was designed to be a flexible solution easy to adapt to different scenarios. We introduced many variables to be able to make this adjustments possible. Major parameters that should be set are: NoOfCopies - initial value of Copies counter, NoOfSecondCopies - initial value of Second Copies counter, FriendDetermine - threshold that determines number of contacts between two nodes that must occurs before they became friend, TTEXPEL - A timer value Time-To-Expire from friendship list for the node which was not met for a longer period, Ffactor, FRankFactor - coefficients used for SocialRank metric calculations defining the ratio between number of friends and their social importance

These are the key parameters which basically differentiates our solution from the others. The optimal value of parameters depends on network size, nodes storage capabilities, TTL etc. To obtain the optimal values of parameters we made many of tests. Based on this, we proposed the optimal values of NoOfCopies = 10 and NoOfSecondCopies = 5. We proposed for friendship determinant value of the threshold set for 5, for number of nodes = 400, TTL = 3600 seconds. All simulation parameters was presented in Table 1.

C. Results

We have run a several simulations tests to evaluate the performance of SocialRouting algorithm. As it was discussed previously the key parameters must be adjusted to the simulated environment. From the protocol family it is well known that replication based protocols usually have higher delivery ratio,
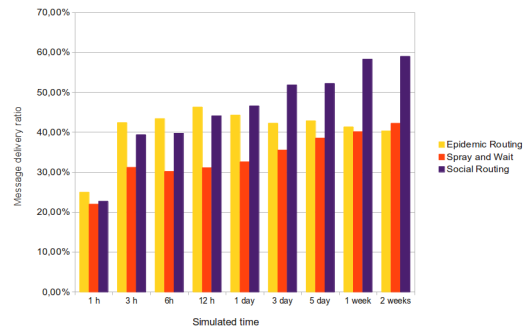

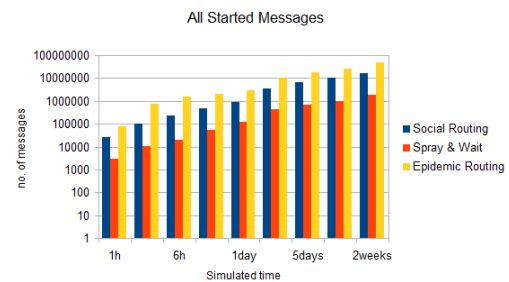Fig. 4. SocialRouting performance compared to SprayAndWait and EpidemicRouting.

Fig. 5. All Started Messages in the Network

while knowledge based algorithms are slightly worst in this case but on the other hand they are less resource-hungry which results in lower costs. In our scenario we considered mobile nodes as real mobile devices with limited storage capacity and low range radio interfaces with fixed bit rate. SocialRouting could be considered as a scheme combining advantages of both routing families. Therefore in its performance evaluation we decided to compare it to two most used routing solutions for DTN which are EpidemicRouting and SprayAndWait. Figure 4 presents the packet delivery ratio we obtained running several simulations with different simulated time.

It could be easily seen that for relatively short simulated time (up to 6 hours) EpidemicRouting has beter performance then SprayAndWait or SocialRouting. The reason is simple: in such a short time there is to small number of message replicas for network congestion. Moreover for these conditions the SocialRouting is working similar to EpidemicRouting because it is imposible to detect the social relations in short time of simulations.

Moreover when longer period simulations are considered it could be clearly concluded that SocialRouting is performing much better than the other two algorithms. For simulated time longer than 1 day a significant improve of delivery ratio for SocialRouting is observed. Thanks to the usage of the social behaviour observations it is possible to gain up to 20% more reliable message exchange.

The cost of high performance of SocialRouting was presented in Figure 5. Figure 5 presents performance in terms of

total number of messages started to send by each algorithm for obtaining a certain message delivery ratio.

V. CONCLUSIONS

This paper presents the SocialRouting the social-based routing algorithm for Delay and Disruptive Tolerant Networks (DTN). The proposed algorithm was extensively analyzed using simulation methods. Simulation results shows, that the proposed algorithm has a better performance than compared solution and it is very attractive in DTN environment.

REFERENCES

[1] K. Fall, A delay-tolerant network architecture for challenged internets, in Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications, SIGCOMM 03, pp. 2734, ACM, 2003, doi: 10.1145/863955.863960

[2] H.-E. Lian, C. Chen, J.-W. Chang, C.-C. Shen, and R.-H. Jan, Shortest path routing with reliability requirement in delay tolerant networks, in Future Information Networks, 2009. ICFIN 2009, pp. 292297, oct. 2009, doi: 10.1109/ICFIN.2009.5339556

[3] E. Jones, L. Li, J. Schmidtke, and P. Ward, Practical routing in delaytolerant networks, Mobile Computing, IEEE Transactions on, vol. 6, pp. 943 959, aug. 2007. doi: 10.1109/TMC.2007.1016

[4] A. Vahdat and D. Becker, Epidemic routing for partially-connected ad hoc networks,, Technical Report CS-200006, 2000.

[5] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, Spray and wait: An efficient routing scheme for intermittently connected mobile networks, In Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking (WDTN '05). ACM, New York, NY, USA, 252-259. doi: 10.1145/1080139.1080143

[6] X. Zhang, J. Kurose, B. N. Levine, D. Towsley, and H. Zhang, Study of a bus-based disruption-tolerant network: mobility modeling and impact on routing, in MobiCom 07: Proc. 13th annual ACM international conference on Mobile computing and networking, pp. 195206, 2007, doi: 10.1145/1287853.1287876

[7] M. Piorkowski, N. Sarafijanovoc-Djukic, and M. Grossglauser, A parsimonious model of mobile partitioned networks with clustering, in Proc. 1st International Conference on COMmunication Systems and NETworkS (COMSNETS), pp. 110, doi: 2009.10.1109/COM-SNETS.2009.4808865

[8] A. Chaintreau, P. Fraigniaud, and E. Lebhar, Opportunistic spatial gossip over mobile social networks, in WOSN 08: Proc. first ACM Workshop on Online Social Networks, 2008, pp. 7378., doi: 10.1145/1397735.1397752

[9] F. Chierichetti, S. Lattanzi, and A. Panconesi, Gossiping (via mobile?) in social networks, in DIAL M-POMC 08, pp. 2728, 2008, doi: 10.1145/1400863.1400870

[10] E. Miluzzo, N. D. Lane, K. Fodor, R. Peterson, H. Lu, M. Musolesi, S. B. Eisenman, X. Zheng, and A. T. Campbell, Sensing meets mobile social networks: the design, implementation and evaluation of the CenceMe application, in SenSys 08: Proc. 6th ACM conference on Embedded network sensor systems, pp. 337350, 2008., doi: 10.1145/1460412.1460445

[11] A. Beach, M. Gartrell, S. Akkala, J. Elston, J. Kelley, K. Nishimoto, B. Ray, S. Razgulin, K. Sundaresan, B. Surendar, M. Terada, and R. Han, WhozThat? evolving an ecosystem for context-aware mobile social networks, IEEE Network, vol. 22, no. 4, pp. 5055, 2008., doi: 10.1109/MNET.2008.4579771

[12] Z.-B. Dong, G.-J. Song, K.-Q. Xie, and J.-Y. Wang, An experimental study of large-scale mobile social network, in Proc. WWW2009, April 2009, doi: 10.1145/1526709.1526915.

[13] P. Hui and J. Crowcroft, How small labels create big improvements, in International Workshop on Intermittently Connected Mobile Ad hoc Networks in conjunction with IEEE PerCom 2007, March 19-23, 2007, doi: 10.1145/1368436.1368478

[14] E. M. Daly and M. Haahr, Social network analysis for routing in disconnected delay-tolerant manets, in ACM MobiHoc 07, 2007, doi: 10.1145/1288107.1288113 ,

[15] P. Hui, J. Crowcroft, and E. Yonek, Bubble rap: Social-based forwarding in delay tolerant networks, in Proc. 9th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), May, 2008., doi: 10.1145/1374618.1374652

[16] W. Gao, Q. Li, B. Zhao, and G. Cao, Multicasting in delay tolerant networks: a social network perspective networks, in Proc. 10th ACM MobiHoc 09, 2009, doi: 10.1145/1530748.1530790 .

[17] Y. Zhang and J. Zhao, Social network analysis on data diffusion in delay tolerant networks, in MobiHoc 09: Proc. tenth ACM international symposium on Mobile ad hoc networking and computing, 2009, doi: 10.1145/1530748.1530806

[18] E. Bulut and B. K. Szymanski, Friendship based routing in delay tolerant mobile social networks, in Proc. IEEE Global Telecommunications Conference (GLOBECOM),, Dec, 2010.

[19] U. B. Shevade, H. H. Song, L. Qiu, and Y. Zhang, Incentive-aware routing in DTNs, in Proc. 16th IEEE International Conference on Network Protocols (ICNP 2008), Orlando, FL, USA, October 2008., doi: 10.1109/ICNP.2008.4697042

[20] A. Mei and J. Stefa, Give2get: Forwarding in social mobile wireless networks of selfish individuals, in ICDCS 10 Proc. 2010 IEEE 30th International Conference on Distributed Computing Systems, 2010., doi: 10.1109/ICDCS.2010.36

[21] H. Zhu, X. Lin, R. Lu, and X. Shen, A secure incentive scheme for delay tolerant networks, in Proc. 3rd International Conference on Communications and Networking in China (ChinaCom), Aug. 2008., doi: 10.1109/CHINACOM.2008.4684961

[22] H. Zhu, X. Lin, R. Lu, Y. Fan, and X. Shen, Smart: A secure multilayer credit-based incentive scheme for delay-tolerant networks, IEEE Trans. Veh. Technol., vol. 58, no. 8, pp. 46284639, Oct. 2009., doi: 10.1109/tvt.2009.2020105

[23] C. BinBin and C. M. Choon, Mobicent: a credit-based incentive system for disruption tolerant network, in Proc. IEEE INFOCOM10, Mar. 2010.

[24] Q. Li, S. Zhu, and G. Cao, Routing in socially selfish delay tolerant networks, in INFOCOM10: Proc. 29th IEEE International conference on Computer Communications, Mar. 2010, doi: 10.1109/INF-COM.2010.5462138

[25] Y. Zhu, B. Xu, X. Shi, A Survey of Social-Based Routing in Delay Tolerant Networks: Positive and Negative Social Effects., IEEE Communications Surveys and Tutorials 15 (1) 2013, 387-401, doi: 10.1109/SURV.2012.032612.00004

[26] Kaimin Wei, Xiao Liang and Ke Xu. "A Survey of Social-Aware Routing Protocols in Delay Tolerant Networks: Applications, Taxonomy and Design-Related Issues", IEEE Communications Surveys and Tutorials, 2013, doi: 10.1109/SURV.2013.042313.00103

[27] H. Jiang, W. Zhuang, and X. Shen, Effective interference control in ultrawideband wireless networks, Vehicular Technology Magazine, IEEE, vol. 1, pp. 39 46, sept. 2006, doi: 10.1109/MVT.2006.307296

[28] M. Freeman, N. Watkins, E. Yoneki, and J. Crowcroft, Rhythm and randomness in human contact, in proc. ASONAM 2010, pp. 184 191, aug. 2010.,DOI: 10.1109/ASONAM.2010.57

[29] A. Keranen, J. Ott, and T. Karkkainen, The ONE Simulator for DTN Protocol Evaluation, in SIMUTools 09: Proceedings of the 2nd International Conference on Simulation Tools and Techniques, ICST, 2009, doi: 10.4108/ICST.SIMUTOOLS2009.5674

[30] F. Ekman, A. Keranen, J. Karvo, and J. Ott, Working day movement model, in MobilityModels 08: Proceeding of the 1st ACM SIGMO-BILE workshop on Mobility models, pp. 3340, ACM, 2008, doi: 10.1145/1374688.1374695