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Overhead Reduction In Delay Tolerant Networks

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Abstract—**Delay tolerant networks (DTN) are sparse wireless networks with intermittent connections due to limited energy, node mobility, propagation and etc. There are various real applications for DTNs such as wildlife tracking, military environment, deep space searching and etc. Traditional routing protocols fail in these networks due to intermittency. DTN protocols are based on store-carry-forward mechanism (SCF). In most of proposed methods, nodes replicate messages and give copies to nodes they encounter. This causes waste of network resources. In proposed algorithm, which is called nearest neighbor visit, for each message, source node has to find the connected neighbor which has the minimum geographic distance to destination. Next hop has to find neighbors which have recently met destination. Comparing NNV to ER and PROPHET, overhead has reduced on average by 85% compared to ER and 50% compared to PROPHET. Also, delivery ratio and delay are maintained in acceptable ranges.**

Keywords-Delay tolerant networks; DTN; message delivery delay; message delivery ratio; overhead

I. INTRODUCTION

Delay tolerant networks (DTNs) are wireless networks with intermittent connections which suffer frequent partitioning [1]. Typical mobile ad hoc networks (MANETs) are not efficient in DTN due to intermittent connectivity, asymmetric delay rates, and etc. DTN routing was first suggested by Fall in 2003 [1-2]. Since then, DTN has found many real applications such as ocean networks [3], vehicular communication networks [4] and space searching [5]. DTN dynamic nature makes routing challenging. Since there is not usually a permanent route between source and destination, store–carry–forward (SCF) mechanism is used for data transmitting [6-8]. SCF tries to find nodes which are suitable for forwarding message. Nodes have to store packet in their buffers while moving in network till an appropriate node for forwarding is found. Regarding limited node resources such as energy, buffer and etc, number of spreading copies should be controlled. Message replication wastes buffer, link bandwidth, energy and etc.

In this paper, a new approach called nearest neighbor visit (NNV) is proposed. This approach tries to find neighbor which is geographically closest to destination and forwards the message. In the next step, the node which has received the packet tries to find the nodes which have recently met the destination. So, it

greatly helps to reduce message overhead compared to flooding approaches while having good performance.

The rest of the paper is organized as follows. Section 2 discusses related works. Section 3 introduces proposed method. Section 4 evaluates proposed method performance. Section 5 concludes the paper.

II. Related Works

Many routing protocols have tried to deal with challenging routing problem. These protocols can be classified from different views. These protocols can be categorized as flooding, forwarding and probabilistic based routing [9].

Flooding protocols distribute messages in network. Epidemic Routing (ER) is the basic form of flooding approaches [10]. It gives a copy of received message to every node it encounters. It tries to reduce delay while wasting bandwidth and buffer. Many researchers have tried to make flooding more efficient. In order to decrease flooding approaches overhead, different methods have been suggested. Spray And Wait is one of well known of these algorithms [11].

Spray And Wait distributes a number of message copies. It consists of two phases. In spray phase, L copies are distributed. Wait phase is similar to direct transmission.

In forwarding protocols, such as minimum estimated expected delay (MEED) [12], a single copy of each message should be forwarded to destination through an efficient path. Different forms of forwarding are discussed in [13].

Probabilistic-based routing uses estimation and probability to increase delivery ratio for finding the best next hop to forward messages. Estimation is based on number of encounters, encounter intervals and etc [14]. Encounters frequency uses the information on how many times nodes meet in network. Probabilistic routing protocol using history of encounters and transitivity (PROPHET) which is an efficient routing protocol is a good example. PROPHET is based on delivery predictability, $P(A,B)$ which belongs to $[0,1]$. This metric estimates the probability that a node delivers the packet to destination using history of encounters with destination. $P(A,B)$ is updated by (1).

$$P(A,B) = P(A,B) + (1 - P(A,B)_{old}) \times P_{initial} \quad (1)$$

$P_{initial}$ is a constant belonging to $(0,1]$. $P(A,B)$ is effected by aging (2).

$$P(A,B) = P(A,B)_{old} \times \gamma^{k} \quad (2)$$

Meeting probability reduces when nodes do not meet each other for a while. Another important factor which affects $P(A,B)$ is transitivity given by (3).

$$P(A,C) = P(A,C)_{old} + (1 - P(A,C)_{old}) \times P(A,B) \times P(A,C) \times \beta \quad (3)$$

MaxProp [15] is also a probabilistic based routing. It uses probability of meeting other nodes which are not necessarily destination. Encounter based routing (EBR) [16], also, uses number of times nodes meet to estimate future encounters.

Aging encounters uses age of encounters. Exponential age search (EASE) [17], Fresher Encounter Research (FRESH) [18] and Spray And Focus [19] use this factor in routing. EASE is an opportunistic forwarding. It uses history of encounters with destination. In FRESH, each node keeps history of last encountered with destination. This helps to find the next hop for forwarding. Nodes have to keep track of their neighbors to update encountered tables. Spray And Focus uses last encounter with destination as a basis for forwarding copies to next hop.

Some routing protocols try to predict node capabilities for contacting to other nodes. This is done by calculating the probability of meeting with other nodes [20] using Kalman filtering [21], semi-Markov [22], theory analysis [23] and etc.

Optimal probabilistic forwarding (OPF) [24] increases delivery predictability by replicating message when encountering with other nodes.

Resource allocation protocols, such as RAPID [25], make forwarding decisions based on available resources.

Social similarity considers social similarities in addition to node movements. Label [26], Simbet [27], Bubble Rap [28], SocialCast [21] and PeopleRank [29] are well known examples of this protocol. Label uses social characters in opportunistic routing. Simbet forwards messages based on nodes which are in the same cluster. Bubble Rap uses community structure and node centrality for forwarding. SocialCast shows forwarding can be done by considering destination interest in addition to social patterns [31]. PeopleRank considers stable social information, social interaction and node mobility for forwarding [31].

III. Proposed Method

DTNs suffer intermittency greatly. This makes routing challenging. In SCF mechanism, nodes have to carry message until finding a suitable hop to forward. This makes buffer queuing delay longer. Also, the packet Time To Live (TTL) can expire and the message has to drop. In order to overcome message drop and finding better opportunities for forwarding, message replication can be used. Despites increasing message delivery ratio, message copies waste node sources such as buffer, bandwidth, buffer and etc. This shows the importance of considering resources while designing routing protocols. Increasing message delivery ratio should be accompanied by controlling number of spread copies. It shows necessity of presenting protocols which try to have good delivery ratio while decreasing network overhead.

In newly proposed approach, nearest neighbor visit (NNV), routing is done in a greedy way.

For each message, source node has to consider the geographic location of connected neighbors. Each node has a geographic location of (x_n, y_n). Geographic coordinate of destination node is given by (x_d, y_d). The source node considers the geographic distance between its connected neighbors and message destination. The message is relayed to node which has minimum distance to destination compared to other

connected nodes. In the next step, the receiving node stores the received message until it finds appropriate hop for forwarding. Appropriate hop in this algorithm is the one which has met the destination recently. The nodes have to record their encounters with other nodes in a table which is implemented in every node. Encounter happens when two nodes are in transmission range of each other. Nodes also have to keep time elapsed since last encounter with each other. This helps to reduce resources usage to set up and maintain routes [32-35]. By recording time and position of last encounter with destination for every node, destination can be found efficiently. Flowchart in Fig.1 shows the implemented algorithm.

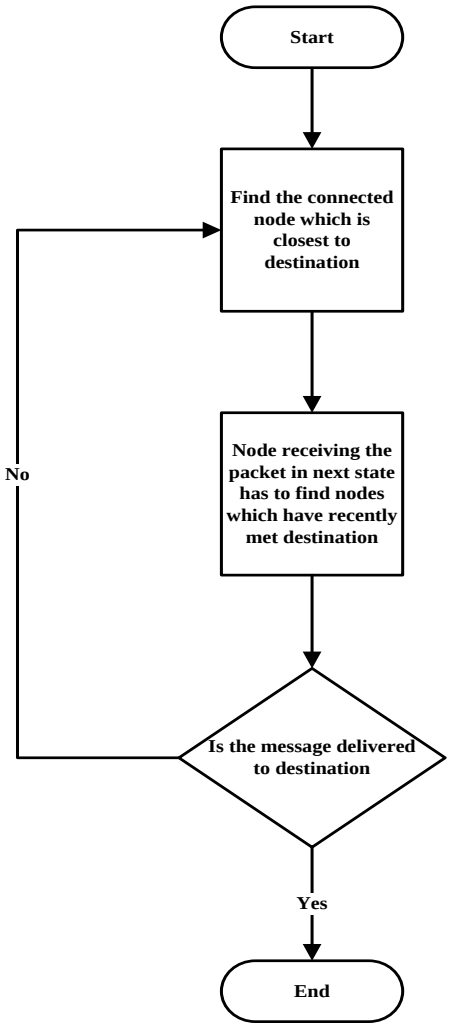

Fig. 1. NNV Flowchart

ER and PROPHET are usually basis for evaluating other algorithms. As illustrated by simulations, NNV helps to reduce overhead compared to ER, PROPHET, Spray And Wait, and Spray And Focus.

DTNs usually use random waypoint (RWP) mobility model which can better show DTN attributes such as sparseness [14]. Inter meeting times of nodes is the gap time between two succeeding following contacts of a pair of nodes. These times are exponentially distributed with inter meeting intensity of λ [36].

$$\lambda = \frac{2\omega RE[V^*]}{L^2} \quad (4)$$

R shows transmission range of nodes. L illustrates square area. $E[V^*]$ shows the average relative speed between two nodes [36]. If minimum speed is equal to maximum speed $(v = v_{min} = v_{max})$, λ can be found by (5) and $\omega = 1.368$ [36]:

$$\lambda \approx \frac{8\omega Rv}{\pi L^2} \quad (5)$$

When M nodes are distributed in $N \times N$ square area $(R \ll L)$ and the nodes are moving under RWP model. The expected meeting times between nodes is given by (6) [37]:

$$EM_{RWP} = \frac{1}{p_m \hat{v}_{RWP} + 2(1-p_m)} \frac{N^2}{2R\bar{L}} \left(\bar{T} + \bar{T}_{pause}\right) \quad (6)$$

$\hat{v}_{RWP} \approx 1.75$ shows node relative speed, $p_m = \frac{\bar{T}}{\bar{T} + \bar{T}_{pause}}$ illustrates probability of node moving [37].

Pause time which belongs to $[0, T_{max}]$ illustrates node pause time after an epoch.

Average speed of a node is given by (7) [38]:

$$\bar{V} = (v_{max} - v_{min}) / (\ln(v_{max}/v_{min})) \quad (7)$$

In the square area, the epoch length, $\bar{L}$ is found by (8) [39]:

$$\bar{L} = 0.5214N \quad (8)$$

Epoch duration is given by (9) [38]:

$$\bar{T} = \bar{L}/\bar{V} \quad (9)$$

Expected delay under RWP is given by (10) [11]:

$$ED_{opt} = \frac{H_{M-1}}{M-1} EM_{RWP} \quad (10)$$

Expected delay in NNV is given by (11) [40]:

$$\text{Expected delay}_{NNV} = \alpha ED_{opt} \quad (11)$$

$(\alpha > 1)$

IV. NNV Evaluation

Simulations are done in Opportunistic Network Simulator (ONE) [41]. ONE is based on Java and it is a good simulator to evaluate routing protocols. Mobility models in ONE show nodes mobility patterns. In this paper simulations are done on UCL database [42] and random generated data.

In order to evaluate NNV, following parameters are considered:

Message delivery ratio: percent of messages delivered to destination.

Message delivery delay: time differences between source creation and delivery to destination.

Relayed messages: Number of successful transmissions between nodes.

Overhead ratio: gives estimation of bandwidth efficiency and is calculated by (10):

$$\text{Overhead ratio} = \frac{\text{Number of Relayed Messages-Number of Delivered Messages}}{\text{Number of Delivered Messages}} \quad (10)$$

In order to evaluate NNV, two scenarios were implemented. In one scenario, UCL database was used to evaluate NNV. Parameter values used for first scenario are shown in Table I.

TABLE I. SCENARIO 1 PARAMETER SETTING

Parameter	Value
Simulation Duration	1036800s = 288h
Number of Nodes	36
Transmission Range	10m
TTL	1440s
Transmission Speed	250k
Speed	[0.8, 1.4 m/s]
Pause Time	[10, 30s]

Simulations are done for 40 times and averages of results are considered. Fig. 2, shows message delivery ratio comparison among ER, PROPHET, NNV, and Spray And Wait.

NNV has increased message delivery ratio compared to PROPHET, ER, and Spray And Wait. NNV delivery ratio in UCL1 is 0.24% higher than ER and Spray And Wait, and 0.33% greater than PROPHET.

Fig. 3, shows overhead ratio comparison among ER, PROPHET, NNV, and Spray And Wait. NNV overhead has decreased by 89.24% compared to ER, 82.87% compared to PROPHET, and 87.1% compared to Spray And Wait. Regarding Fig. 2 and Fig. 3, overhead has decreased considerably while maintaining message delivery ratio in good stage.

Fig. 4, shows message delivery delay comparison among ER, PROPHET, NNV, and Spray And Wait. NNV delivery delay has decreased by 6% compared to ER and 3.23% compared to Spray And Wait.

Considering Fig. 4, PROPHET has the same delay in comparison to NNV. This simulation reveals that NNV can successfully reduce overhead while maintaining message delivery ratio and delivery delay in good range.

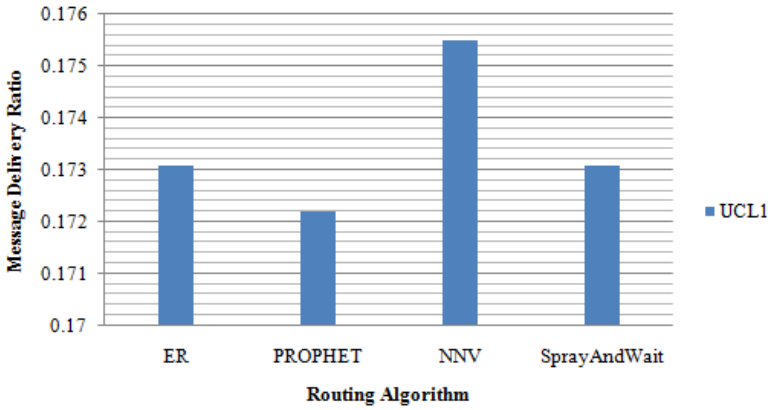

Fig. 2. Message delivery ratio comparison among ER, PRoPHET, NNV, and Spray And Wait

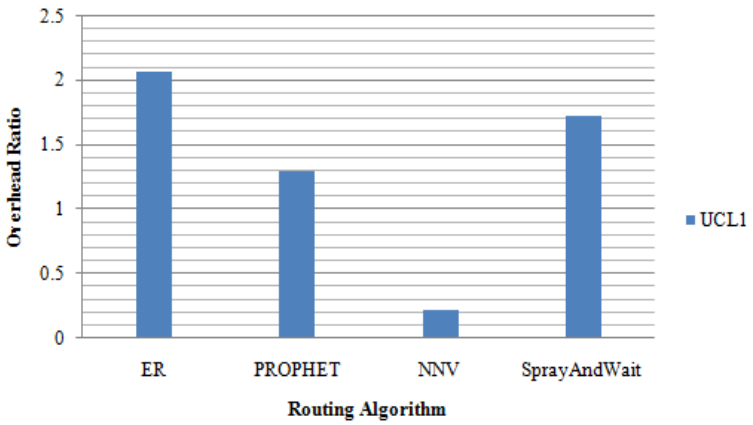

Fig. 3. Overhead ratio comparison among ER, PRoPHET, NNV, and Spray And Wait

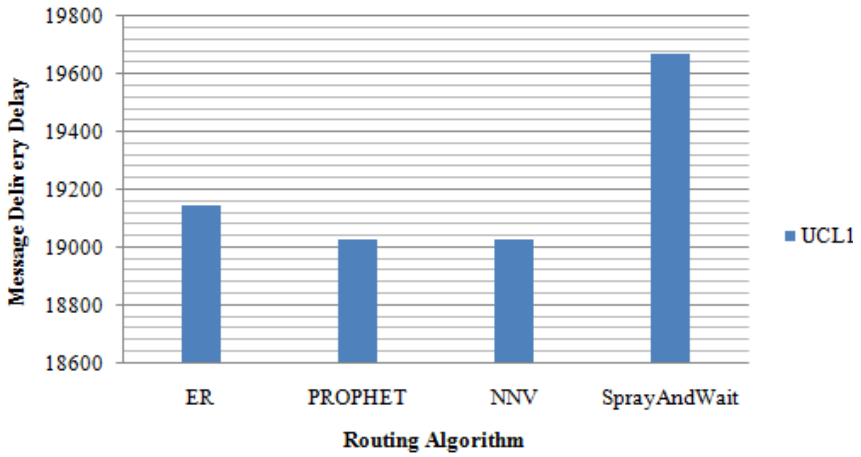

Fig. 4. Message delivery delay comparison among ER, PRoPHET, NNV, and Spray And Wait

In second scenario, random data is used. 100 nodes are scattered in an area of $4000\times4000m^2$. Random data movement is based on RWP [38]. RWP states node mobility in random direction. Simulations in this part are also repeated for 40 times and the average results are considered for evaluation. In one experiment, message time to live (TTL) was varied from 100s to 1000s. Parameter settings are shown in Table II.

TABLE II. SCENARIO 2, CHANGING TTL

Parameter	Value
Simulation Duration	43200s = 12h
Number of Nodes	100
Transmission Range	10m
TTL	100s-1000s
Transmission Speed	250k
Speed	[0.8, 2 m/s]
Pause Time	[0,120s]
Message size	100B;200B
Buffer Size	10M

Message delivery ratio, overhead and message delivery delay are evaluated regarding TTL changes. Overhead ratio comparison is shown in Fig. 5. NNV overhead has reduced on average by 88.75% compared to ER, and 50% less than PROPHET. NNV delay is 2% less than Spray And Wait when TTL is greater than 300s. NNV has also reduced overhead by 2% compared to Spray and Focus. As it can be observed in Fig. 5, when TTL is less than 300s, NNV still lessens overhead ratio compared to Spray And Wait on average of 83.3%.

This is a great advantage for NNV to reduce overhead even for short message TTLs.

Message delivery delay is shown in Fig. 6. NNV delay has become shorter on average by 25% compared to ER and PROPHET. It has improved by 5% compared to Spray And Wait. In this experiment, Spray And Focus has approximately the same delay as NNV when TTL is greater than 400s.

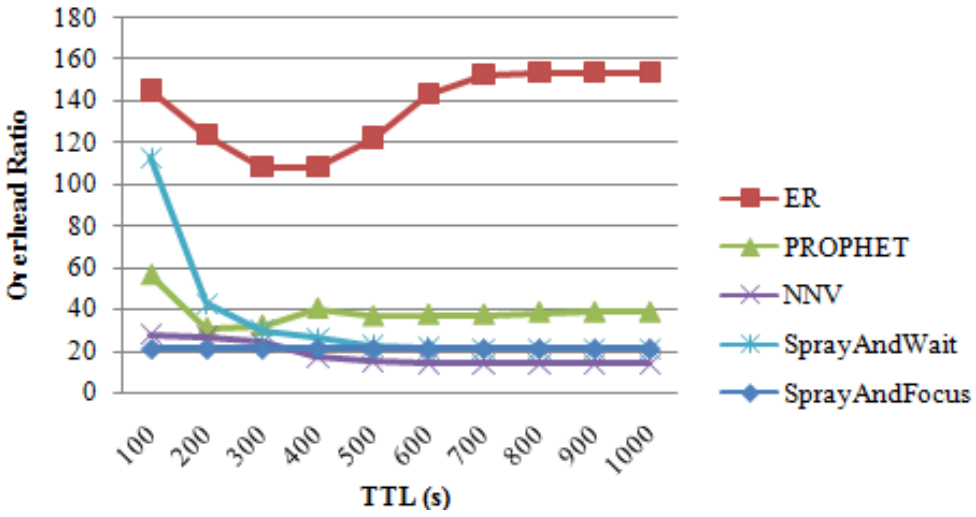

Fig. 5. Overhead ratio comparison among ER, PRoPHET, Spray And Wait, Spray And Focus, NNV in RWP regarding TTL changes

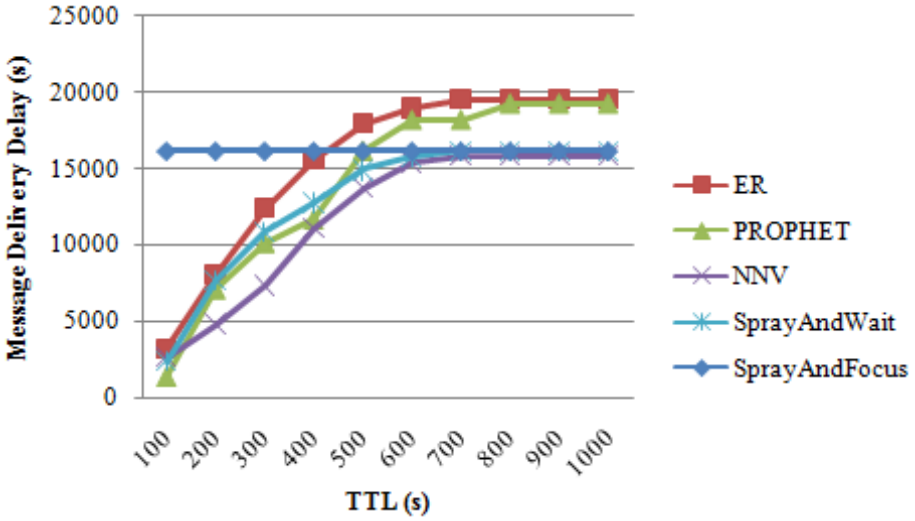

Fig. 6. Message delivery ratio comparison among ER, PRoPHET, Spray And Wait, Spray And Focus, NNV in RWP regarding TTL changes

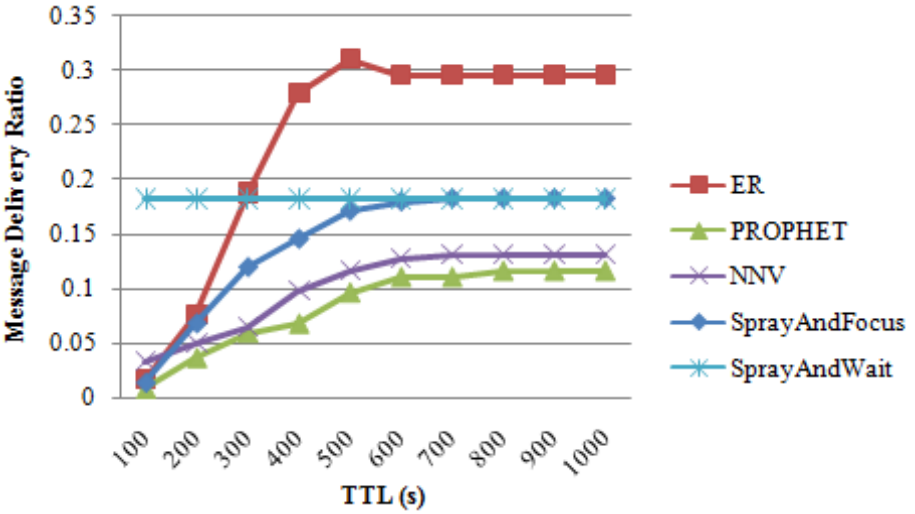

Fig. 7. Message delivery delay comparison among ER, PRoPHET, Spray And Wait, Spray And Focus, NNV in RWP regarding TTL changes

When TTL is less than 400s, NNV delay has reduced by 25% compared to Spray And Wait and 50% less than Spray And Focus. Decreasing delay even for short TTLs, shows positive effect of NNV. Message delivery ratio is shown in Fig. 7.

NNV delivery ratio has been improved compared to PROPHET by 50%. As it can be observed in Fig. 5 and Fig. 6, NNV overhead and delay has improved while keeping message delivery ratio in a good value. ER which shows better delivery ratio, wastes node sources greatly as was mentioned previously.

Since NNV tries to reduce overhead, packet copy spreading in network is limited. This is the reason of reduction in message delivery ratio compared to Spray And Wait and Spray And Focus.

It is important to notice that message delivery reduction is not noticeable and delivery ratio in NNV is greater than PROPHET. Although overhead has been reduced, message delivery ratio is not disturbed considerably compared to Spray And Wait and Spray And Focus. NNV seems efficient in this scenario. In addition to TTL changes, buffer size variation is also studied in another observation. Parameter settings are found in Table III.

TABLE III. SCENARIO 2, CHANGING BUFFER SIZE

Parameter	Value
Simulation Duration	43200s = 12h
Number of Nodes	100
Transmission Range	10m
TTL	300s
Transmission Speed	250k
Speed	[0.8, 2 m/s]
Pause Time	[0,120s]
Message size	100B;200B
Buffer Size	100M-1000M

Buffer size varies from 100M to 1000M and following results are observed.

Regarding Fig. 8, NNV overhead has reduced on average by 33% compared to PROPHET and Spray And Wait, and 77.8% compared to ER. NNV has reduced overhead by 28.33% compared to Spray And Focus.

As shown in Fig. 9, delay has decreased an average of 37.5% compared to Spray And Focus. NNV delay is 16.7% less than ER and 3.6% less than Spray And Wait. PROPHET has shown similar results to NNV.

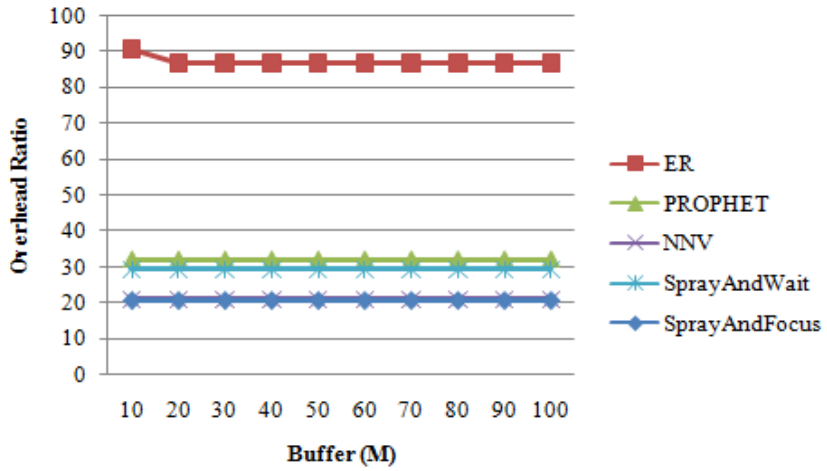

Fig. 8. Overhead ratio comparison among ER, PRoPHET, Spray And Wait, Spray And Focus, NNV in RWP regarding buffer changes

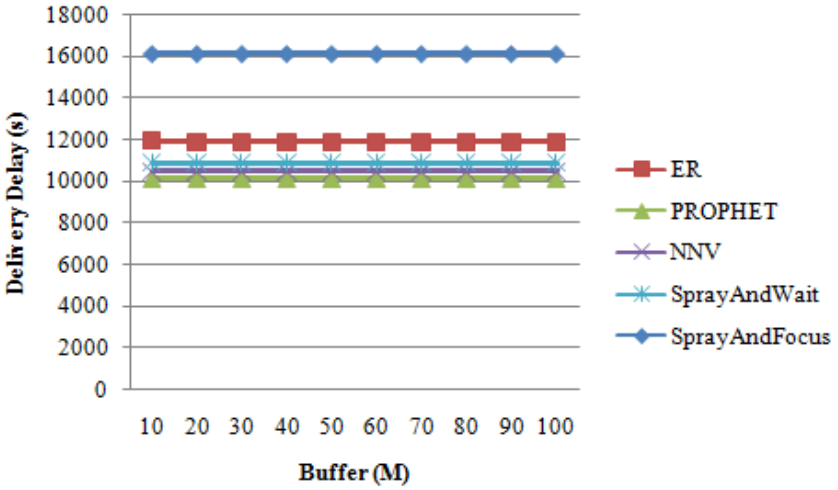

Fig. 9. Message delivery delay comparison among ER, PRoPHET, Spray And Wait, Spray And Focus, NNV in RWP regarding buffer changes

Message delivery ratio is shown in Fig. 10. NNV has increased message delivery ratio by 16% compared to PROPHET. NNV has not considerably disturbed delivery ratio compared to ER, Spray And Wait, and Spray And Focus.

The reason which explains the message delivery reduction is limited number of spread copies in the network

Flooding approaches increase message delivery while wasting network sources and increasing overhead.

NNV has reduced overhead and delay while maintain good message delivery ratio. It greatly helps to preserve node sources. This experiment also proves NNV success in reducing overhead while maintaining message delivery ratio in an acceptable range

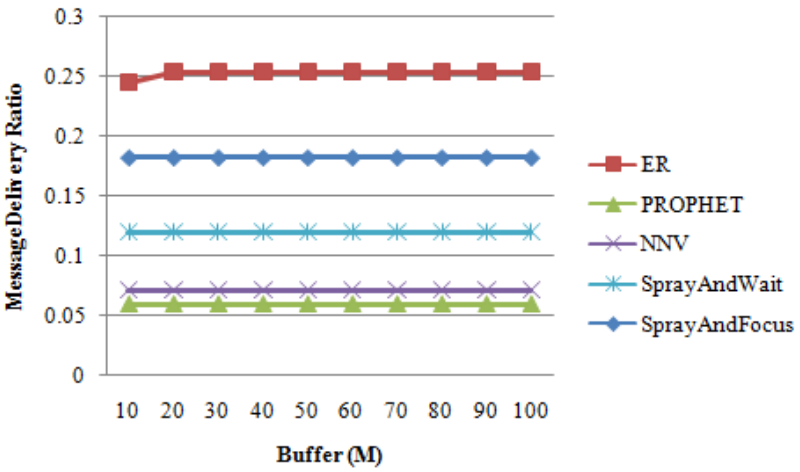

Fig. 10. Message delivery ratio comparison among ER, PRoPHET, Spray And Wait, Spray And Focus, NNV in RWP regarding buffer changes

V. Conclusion

Delay tolerant networks (DTNs) are sparse wireless networks with intermittent connections. Routing in such networks is challenging. In this paper, a new routing protocol, called nearest neighbor visit (NNV) is proposed. Due to limited sources of nodes, it tries to reduce overhead while maintaining good message delivery ratio. NNV tries to find connected neighbors which are geographically closest to destination and sends the message to it. The receiving node, forwards the message to nodes which have recently met the destination. This will greatly reduce delay and overhead. In order to evaluate proposed method, NNV was compared to ER, PROPHET, Spray And wait, and Spray And Focus. Experiments were done on UCL data base and random values. Simulation results proved that NNV has reduced overhead and delivery delay while keeping message delivery ratio in acceptable range.

Future work will concentrate on using evolutionary algorithms (EA). These algorithms can help to find appropriate adjacent nodes for forwarding messages toward destination. Transmission range, number of copies and buffer size can also be found by EA.

References

[1] K. Fall, "A delay-tolerant network architecture for challenged Internets," In: ACM 2003 Conference on Applications, technologies, architectures, and protocols for computer communications, ser. SIGCOMM'03, New York, USA, pp. 27-34, 2003.

[2] M. Ho and K. Fall, "Poster: Delay tolerant networking for sensor networks," In: IEEE 2004 Conference on Sensor and Ad Hoc Communications and Networks, 2004.

[3] J. Partan, K. Kurose, and B.N. Levine, "A survey of practical issues in underwater networks," In: ACM 2006 WUWNet, September 2006, pp. 17-24, 2006.

[4] J. Ott and D. Kutscher, "A disconnection tolerant transport for drive-thru Internet environments," In: IEEE 2005 INFOCOM, 13-17 March 2005, vol. 3, pp. 1849-1862, 2005.

[5] T. Small and Z.J. Haas, "The shared wireless information model: a new ad hoc networking paradigm," In: ACM 2003 MobiHoc, pp. 233-244, 2003.

[6] S. Jain, K. Fall, and R. Patra, "Routing in a delay-tolerant network," In: ACM SIGCOMM 2004, Portland, USA, vol. 34, no. 4, pp. 145-158, 2004.

[7] Z. Zhang, "Routing in intermittently connected mobile ad hoc networks and delay-tolerant networks," Overview and challenges. Commun. Surveys Tuts. vol. 8, no. 1, pp. 24-37, 2006.

[8] K. Fall and S. Farrell, "DTN: An architectural retrospective," IEEE J. Sel. Areas Commun. vol. 26, no. 5, pp. 828-836, 2008.

[9] D. Hua, X. Du, Y. Qian, and S. Yan, "A DTN routing protocol based on hierarchy forwarding and cluster control," In: 2009 International conference on computational Intelligence and security, 11-14 December 2009, Beijing, pp. 379-401, 2009.o

[10] A.Vahdat and D. Becker, "Epidemic routing for partially connected ad hoc networks," Duke University, Tech. Rep. CS.-2000-06, July 2000.

[11] T. Spyropoulos, K. Psounis, and C.S. Raghavendra, "Spray and wait: an efficient routing scheme for intermittently connected mobile networks," In: SIGCOMM 2005 WDTN, August 2005, Philadelphia, USA, pp. 252-259 , 2009.

[12] E.P.C. Jones, L. Li, and P.A.S. Ward, "Practical routing in delay-tolerant networks," In: ACM 2005 SIGCOMM WDTN, August 2005, Philadelphia, USA, vol. 6, no. 8, pp. 943-959, 2005.

[13] T. Spyropoulos, K. Psounis, and C.S. Raghavendra, "Efficient routing in intermittently connected mobile networks: the single-copy case," IEEE/ACM; Trans. Netw. vol. 16, no. 1, pp. 63-76, 2008.

[14] A. Lindgren, A. Doria, and O. Scheln, "Probabilistic routing in intermittently connected networks," Lecture Notes in Computer Science, vol. 3126, pp. 239-254, 2004.

[15] J. Burgess, B. Gallagher, D. Jensen, and B.N. Levine, "Maxprop: Routing for vehicle-based disruption-tolerant networks," In: INFOCOM 2006, April 2006, Barcelona, Spain, pp. 1-11, 2006.

[16] S. Nelson, M. Bakht, and R. Kravets, "Encounter-based routing in DTNs," In INFOCOM 2009, 19-25 April 2009, Rio de Janeiro, Brazil, pp. 846-854, 2009.

[17] M. Grossglauser and M. Vetterli, "Locating mobile modes with EASE: Learning Efficient routes from encounter histories alone," IEEE/ACM Trans. Netw. vol. 14, no. 3, pp. 457–469, 2006.

[18] H. Dubois-Ferriere, M. Grossglauser, and M. Vetterli, "Age matters: efficient route discovery in mobile ad hoc networks using encounter ages," In: ACM 2003 MobiHoc, June 2003, Annapolis, USA, 2003.

[19] T. Spyropoulos, K. Psounis, and C.S. Raghavendra, "Spray and focus: Efficient mobility-assisted routing for heterogeneous and correlated mobility," In: IEEE 2007 PERCOM Workshops, 19-27 March 2007, White Plains, USA, pp. 79-85, 2007.

[20] W. Gao and T.L. Porta, "On exploiting transient social contact patterns for data forwarding in delay-tolerant networks," IEEE Trans. Mob. Comput. vol. 12, no. 1, pp. 151-165, 2013.

[21] P.Costa, C. Mascolo, M. Musolesi, and G.P. Picco, "Socially Aware routing for publish-subscribe in delay-tolerant mobile ad hoc networks," IEEE J. Select. Areas Commun. vol. 26, no. 5, pp. 748-760, 2008.

[22] Q. Yuan, I. Cardei, and J. Wu, "Perdict and Relay: An efficient routing in disruption-tolerant networks," In: ACM MobiHoc, pp. 95-104, 2009.

[23] H. Cai and D.Y. Eun, "Crossing over the bounded domain: from exponential to power-law inter-meeting time in MANET," In: ACM Mobicom, pp. 159-170, 2007.

[24] C. Liu and J. Wu, "An optimal probabilistic forwarding protocol in delay tolerant networks," In: ACM 2009 MobiHoc, May 2009, New Orleans, USA, pp. 105-114, 2009.

[25] A. Balasubramanian, B. Levine, and A. Venkataramani, "DTN routing as a resource allocation problem," In: ACM 2007 SIGCOMM, 27-31 August 2007, Kyoto, Japan, pp. 373-384, 2007.

[26] P. Hui and J. Crowcroft, "How small labels create big improvements," In: IEEE 2007 PERCOM Workshops, March 2007, White Plains, USA, pp. 65-70, 2007.

[27] E. M. Daly and M. Haahr, "Social network analysis for routing in disconnected delay-tolerant MANETs," In: ACM 2007 MobiHoc, September 2007, Montreal, Canada, pp. 32-40, 2007.

[28] P. Hui, J. Crowcroft, and E. Yoneki, "Bubble Rap: social-based forwarding in delay tolerant networks. In: ACM 2008 MobiHoc, May 2008; Hong Kong, China, pp. 241-250, 2008.

[29] A. Mtibaa, M. May, M. Ammar, and C. Diot, "Peoplerank: Combining social and contact information for opportunistic forwarding" In: INFOCOM, San Diego, USA, March, 2010.

[30] W. Moreira and P. Mendes, "Survey on opportunistic routing for delay/disruption tolerant networks," SITI Tech. Rep. SITI-TR-11-02, 2010.

[31] D. B. Johnson and D. A. Maltz, "Dynamic source routing in ad hoc wireless networks," Imielinski and Korth, editors, Mobile Computing, Kluwer: Academic Publishers, vol. 353, pp. 153-181, 1996.

[32] C. E. Perkins and M. E. Royer, "Ad hoc on-demand distance vector routing," In: IEEE 1999 2nd Workshop on Mobile Computing Systems and Applications, 25-26 February 1999, New Orlands, LA, USA, pp. 90-100, 1999.

[33] G. Aggelou and R. Tafazolli, "RDNNV: A bandwidth-efficient routing protocol for mobile ad hoc networks," In: Second ACM 1999 International Workshop on Wireless Mobile Multimedia, August 1999, Seattle, WA, pp. 26-33, 1999.

[34] C. Chiang, H. Wu, W. Liu, and M. Gerla, "Routing in clustered multihop, mobile wireless networks," In: IEEE 1997 Signapore International Conference on Networks, Signapore, pp. 197-211, 1997.

[35] V. D. Park and M. S. Corson, "A highly adaptive distributed routing algorithm for mobile wireless networks," In: IEEE 1997 Conference on Computer Communications (INFOCOM), Kobe, Japan, April 1997, pp. 1405-1413, 1997.

[36] R. Groenevelt, "Stochastic models in mobile ad hoc networks," Ph.D. dissertation, University of Nice Sophia Antipolis, 2005.

[37] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Performance analysis of mobility-assisted routing," In: ACM MobiHoc, pp. 49–60, 2006.

[38] J. Yoon, M. Liu, and B. Noble, "Random waypoint considered harmful," In: Twenty-Second Annual Joint Conference of the IEEE Computer and Communications (IEEE INFOCOM), vol. 2, pp. 1312- 1321, 2003.

[39] C. Bettstetter, H. Hartenstein, and X. P'erez-Costa, "Stochastic properties of the random waypoint mobility model: Epoch length, direction distribution, and cell change rate," In: The 5th ACM international workshop on Modeling analysis and simulation of wireless and mobile systems (MSWIM'02), pp. 7-14, 2002.

[40] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Efficient routing in intermittently connected mobile networks: The multiple-copy case," IEEE/ACM Transactions on Networking, vol. 16, no. 1, pp. 77-90, 2008.

[41] A. Keränen, T. Kärkkäinen, and J. Ott, "Simulating mobility and DTNs with the ONE," J Commun. vol. 5, no. 2, pp. 92-105, 2010.

[42] http://www.shigs.co.uk/index.php?page=traces, Accessed 20 June 2013.

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