Journal of Computer Science 7 (7): 1038-1045, 2011
ISSN 1549-3636

Integrating Buffer Management with Epidemic Routing in Delay Tolerant Networks

[1]G. Fathima and [2]R.S.D. Wahidabanu
[1]Department of Information Technology,
Adhiyamaan College of Engg, Hosur. TamilNadu, India
[2]Department of Electronics and Communication Engg,
Govt. College of Engg, Salem. TamilNadu, India

Abstract: Problem statement: The Design of Delay Tolerant Network (DTN) routing protocols has focused to operate in an environment where there is no guarantee of end to end path between source and destination at all points of time. The DTN research has focussed primarily on applications that are delay tolerant. But it can also be used to provide real time information like accident alert in VANETs and emergency alert in earth-quake monitoring applications. Such environment stimulates the need to introduce priority to messages and deliver them at the earliest according to the priority. **Approach:** In this study, an effective buffer management is proposed and integrated to epidemic routing to support delivery of real-time information at the earliest. In the proposed approach, an indexer, scheduler and dropper is used to perform the buffer management. **Results and Conclusion:** The performance of epidemic routing after integration is evaluated and compared with other policies in terms of metrics such as delivery ratio and delivery latency. The simulation results show that the approach presented performs well with an advantage of delivering real-time information at the earliest.

Key words: Delay tolerant networks, routing protocols, prioritization of messages, delivery ratio, delivery latency, epidemic routing, simulation results, buffer management

INTRODUCTION

Mobile Ad Hoc Networks (MANETs) are infrastructure-less and nodes in the network are constantly moving. Node mobility in MANETs causes frequent change in topology of the network. To accommodate the dynamic topology of MANETs, an abundance of routing protocols like OLSR (Clausen *et al*., 2003), AODV (Perkins, 2003), DSR (Johnson and Maltz, 1996), ODMRP (Lee *et al*., 2001), LAR (Ko and Vaidy, 2000) and many variations to the original MANET routing protocols (Natsheh and Buragga, 2010) have also been proposed. A review of these protocols (Geetha and Gopinath, 2007) is studied. All these protocols operate based on assumption that the network is always connected and there exists end-to-end path between any source and destination pair. But this assumption fails in certain applications like deep space networks, military ad hoc networks and wireless sensor networks where the connectivity is often intermittent due to node mobility, power conservation, disaster etc., To enable communication even under such challenging environments, researchers proposed a new network paradigm called Delay-Tolerant Networking. It operates based on the principle of store-carry and forward routing. i.e., DTNs offer asynchronous communication where messages are sent to the intermediate nodes, which is stored by them until a suitable next hop or the destination is available for forwarding. The details of delay tolerant network architecture are available in (Fall, 2007).

MATERIALS AND METHODS

The DTN approach is well suited for deploying applications in the developing world as it allows applications to continue to operate with much less infrastructure compared with more traditional networking approaches. There are many applications that make use of DTN like (i) low-cost internet provision in remote or developing communities (Pentland *et al*., 2004), (ii) vehicular networks (VANETs) for dissemination of location dependent information (eg., local ads, traffic reports, parking information (Basu and Little, 2002)), (iii) noise monitoring and earth quake monitoring etc., From the literature survey (Jones *et al*., 2007; Zhang, 2006; Daly and Haahr, 2010; Farrell *et al*., 2006), it is understood

Corresponding Author: G. Fathima, Department of Information Technology, Adhiyamaan College of Engg, Hosur. TamilNadu, India

that a large amount of research has been performed in developing efficient routing algorithms for DTNs.

The environment that is considered in this study is rural and sparse areas with low node densities and high node mobility. In such areas, there is very little or no fixed infrastructure available. Only mobility of the node is exploited to deliver the messages. The DTN research has focussed primarily on applications that are delay tolerant. But they can also be used to provide real time information like accident alert in VANETs and emergency alert in earth-quake monitoring applications. Such environment stimulates the need to introduce priority to messages and deliver them at the earliest according to the priority.

DTNs operate with the principle of store, carry and forward. Messages are buffered before they are forwarded to next node encountered. As the scenario considered in this study consists of network with low node density and high node mobility, the duration of contact is small. Moreover the bandwidth is considered to be limited. A critical issue here is (i) to select messages from the buffer that are to be transmitted within the available short duration of contact (ii) to drop messages from the buffer selectively when the buffer overflows. Both of which requires an effective buffer management. In this study, an indexer, scheduler and dropper is proposed to manage the buffer. The proposed buffer management is integrated with Epidemic routing as it is the better choice in view of successful delivery in DTNs.

Epidemic routing and buffer management: There are various routing protocols available for DTN. Generally the routing protocols of DTN differ in the knowledge that they use in making routing decisions and the number of replication they make. The various DTN protocols are Direct Delivery routing, First Contact routing, Epidemic routing, Spray and Wait routing, PRoPHET routing and MaxProp routing. Among the above mentioned protocols, the first four protocols are simple routing protocols which don't require any knowledge about the network. The latter two protocols use some extra information to make decisions on forwarding. As the network considered is sparse and no knowledge about the network is known, epidemic routing is considered as the dominant choice. Moreover unlike other protocols, it does not rely on mobility or location information to aid in routing decision. Comparison of different DTN routing protocols and their buffer utilization (Fathima and Wahidabanu, 2010a) is studied.

Epidemic routing: The proposed approach is motivated by the properties of Epidemic routing. The Epidemic routing (Alan *et al*., 1987; Vahdat and Becker, 2000) is based on flooding. It floods the message to all its neighbors. Then it relies on neighbors to transmit messages through flooding. This would result in maximal spreading of the messages throughout the network and therefore achieves high delivery probability. But it consumes a lot of resources. Though Spray and Wait routing (Spyropoulos, 2005; Spyropoulos *et al*., 2008) works a bit like Epidemic but it restricts the amount of copies that are spread in the network. Thereby it restricts the excess use of resources. But it has less delivery ratio compared to that of Epidemic routing.

Buffer management and related work: Buffer management is a fundamental technology which controls the assignment of buffer resources among different traffic classes and aggregation of the same according to certain policies. An efficient buffer management policy is required to decide at each step which of the messages is to be dropped when buffer is full and which of the messages are to be transmitted when bandwidth is limited irrespective of the routing algorithms used.

The protocols like Direct Delivery and First Contact routing are single copy protocols where only one copy per message is routed in FCFS order. i.e., the messages are transmitted in the order in which they were stored in the buffer. Among the replication based protocols, Epidemic and Spray and Wait routing also uses FCFS forwarding policy. PRoPHET (Lindgren *et al*., 2004) routing makes forwarding decision based on delivery predictability of the destination. It needs history of past encounters for calculation of delivery predictability. MaxProp (Burgess *et al*., 2006) routing assigns priorities to the messages based on hop count and delivery likelihood. Estimation of delivery likelihood is done based on historical data. It forwards the messages with high priorities when a contact arises. RAPID (Aruna *et al*., 2007) protocol derives the per-packet utility function from administrator-specified routing metric. It forwards the messages with highest utility value first. Similarly, the Optimal policy in (Amir *et al*., 2008a; 2008b; David and Giaccone, 2009) derives per-message utility function from statistical learning and the message with smallest utility is dropped when the buffer is full and message with highest utility is scheduled first for transmission. In Prioritized Epidemic Routing (Ram *et al*., 2007), each bundle is assigned a drop priority and transmit priority which is based on hop count. i.e., the number of hops the bundle has traversed thus far. The transmission and dropping is done based on the priority. The previous work (Fathima and Wahidabanu, 2010b) classifies the bundles based on Class of Service. The approach presented in this study differs from the above mentioned works in considering the priority specified by the application and lifetime of the bundles.

The simple dropping policy used in many networks is drop tail policy. Apart from drop tail policy there are other policies proposed in the literature (Davids *et al*., 2001; Lindgren and Phanse, 2006) like Drop Old (DO), Drop Young (DY) and Drop Random (DR). Upon arrival of a packet the system can decide to either accept the packet or reject it or accept it and drop another packet based on the policy. Though a number of dropping policies are possible, it is studied from literature that DO gives better performance than other policies. But it does not provide any mechanism for storing high priority messages.

Similarly, though a number of scheduling policies are possible, FCFS is the simple policy which is easy to implement. As long as the contact duration is long enough to transmit all messages a node has, FCFS is a very reasonable policy. However if the contact duration is limited, FCFS is sub-optimal as it does not provide any mechanism for preferential delivering of high priority messages. Considering the above said problems, the goal is to determine the policy which maximizes the overall throughput or equivalently minimize the overall loss probability of high priority messages. Therefore the proposed approach attempts to differentiate traffic based on priority and provide better levels of service in a best-effort environment. The proposed approach is more advantageous in emergency applications as it does preferential delivery with least delay.

Proposed approach of buffer management: Most of the existing routing protocols offer best effort service. There is one fundamental limitation of best effort method being used: it makes no attempt to differentiate the traffic that is generated by different hosts. But to provide different services to different applications, it is necessary to differentiate traffic. For e.g, an alert about the accident is more important than the regular findings. Moreover there may be some messages in the buffer whose lifetime is small and delivering them at the earliest is more important according to their priority. Therefore a buffer management mechanism is required which is capable of transmitting and dropping messages preferentially so as to maximize the delivery ratio or minimize end to end latency. A motivation for the proposed approach is to provide a means by which applications that are not intrinsically delay tolerant can still be supported by DTN deployment to deliver real time information.

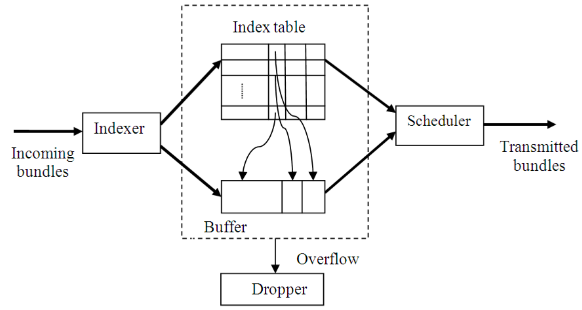

Fig. 1: Buffer management system-overview

The network that is considered can be characterized as partially connected with low node density and high node mobility. The movement inherent in the nodes themselves is exploited to deliver the messages when the network is partially connected. Assume that N is the total number of nodes in the network. Each of these nodes has a buffer, which can store either messages belonging to other nodes or messages generated by itself. Each message is destined to one of the nodes in the network and has a Time-To-Live (TTL)/lifetime value. Once the TTL value expires, the message is no more useful to the application and it is dropped from the buffer. In DTN, bundle protocol is used for transfer of messages. A bundle is a protocol data unit of the DTN bundle protocol (Scott and Burleigh, 2007). The bundle with real-time information is set to high priority. The lifetime field available in the primary bundle block gives the expiration time.

The proposed buffer management system comprises of (i) Bundle indexer which assigns index to bundles according to their priority and the lifetime. (ii) Bundle scheduler which is invoked when the contact opportunity arises and schedules the bundles based on indexing (iii) Bundle dropper which is invoked when buffer is full and drops the bundle based on indexing value. This system is illustrated in Fig. 1.

Bundle indexer: It maintains the index table. The table contains a set of information stored with bundle id such as lifetime, priority, source id, destination id of the bundle and a pointer pointing the actual bundle. The entire bundle is stored in the buffer. Initially bundles are indexed according to the priority and the lifetime and stored in appropriate entry in the index table. The Bundle Indexer is a function of newly arrived bundle and the bundles in the index table. The bundle with lowest index has highest precedence.

Bundle dropper: When the entire buffer is full, some of the bundles should be dropped to give room for new bundles. So once the buffer is full, the Bundle dropper is invoked. A bundle is dropped automatically when the TTL expires. It is also taken care that a node should not drop its own bundle (source) to give room for newly arrived bundles. The idea of giving priority to source bundles has been proposed in previous studies and was shown to improve the average delivery ratio. So the same idea is followed here. Bundle dropping is a function which identifies the bundle to be dropped based on indexing value. The policy followed for dropping is to drop the bundle with highest index value.

Bundle scheduler: In Epidemic routing, summary vector is maintained at each node which represents the buffered messages at that node. Initially, only summary vector is exchanged when two nodes come into the communication range of each other to know the bundles that are already available. In the proposed approach, summary vector is not maintained. Instead, only bundle ids from the index table are exchanged between each other. Short duration of contact between the nodes and finite bandwidth may not allow the node to transmit all the messages that are available in the buffer. Moreover, some bundles have real-time information which is to be sent earlier. In such cases the order in which the messages are transmitted is significant. Bundle scheduler transmits the bundles from lowest index to highest index.

It should be noted that irrespective of the scheduling policy adopted, the messages whose destination encountered are the first to be transmitted and the same may be deleted from the buffer. This increases the delivery ratio as well as gives room for new bundles. Nodes do not delete bundles that are forwarded to other nodes (i.e., not to destination) as long as there is sufficient space available in the buffer. By scheduling the bundles based on the priority, the best effort service can be enhanced. It is more practical to implement. Performance of DTN is measured in terms of average delivery ratio and average delivery latency which are defined as follows:

- Delivery ratio is defined as ratio of number of messages delivered to the destination to the total number of messages sent by the sender
- Delivery latency is defined as the average of time taken to reach from source to destination by all messages

RESULTS

To evaluate the proposed approach, the ONE Simulator has been used. ONE is an Opportunistic Network Environment simulator which is designed specifically for DTN environment. It is a discrete event based simulator. It is a Java-based tool which provides DTN protocol simulation capabilities in a single framework. A detailed description of this simulator is available in (Keranen, 2008). The Mobility model used is Random Way Point (RWP) model. It is the model in which nodes move independently to a randomly chosen destination. As the network with random behaviour is considered, Epidemic routing is used as the routing algorithm.

The simulation environment consists of sparsely distributed mobile nodes and they communicate when they are in the communication range of one another. The settings of the nodes like buffer size, transmit range, transmit speed, node speed, wait time, number of nodes are set as mentioned in the Table 1.

The performance of epidemic routing under different buffer management policies is compared in terms of metrics like delivery probability and average delivery latency. Simulation results for different dropping policies with FCFS as the scheduling policy with respect to delivery probability are shown in the Fig. 2. The different policies that are compared are Drop Old (DO), Drop Young (DY), Drop Random (DR) and Proposed Policy (PP). It can be observed from the result that as and when the traffic load increases, the delivery probability decreases irrespective of the policies. At the same time, it also ensures that the delivery ratio does not get reduced upon incorporating the Proposed Policy (PP), when compared to other policies due to increase in overhead. But it guarantees the delivery of high priority messages first which is confirmed through the results of simulation. When compared to other approaches from the literature, the proposed approach has the overhead of maintaining the index table. But it has the credit of delivering real-time information with less delay. The proposed policy is more advantageous when there is strict constrains on resources like buffer and bandwidth.

It has been shown in previous studies that DO policy gives better performance in terms of delivery ratio among the different drop policies used with epidemic routing. The simulation results shown in Fig. 2 support it.

Table 1: Parameters

Parameters	Values
No.of Nodes	100
Transmit Range (m)	250
Transmit speed (Mbps)	2
Node Speed (km/hr)	10-60
Message size (MB)	1-2
TTL of message (min)	30
Buffer size (MB)	15

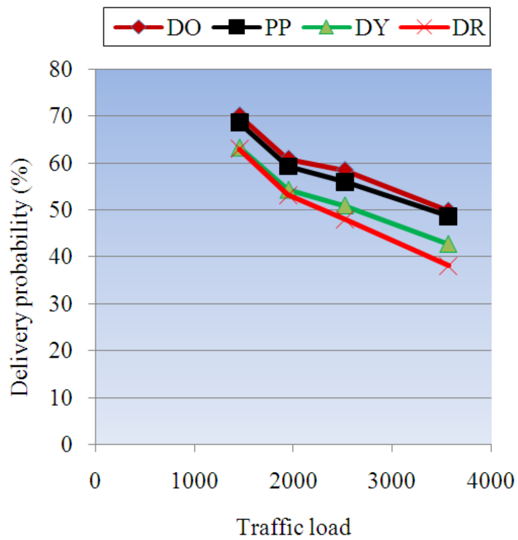

Fig. 2: Delivery probability Vs traffic load

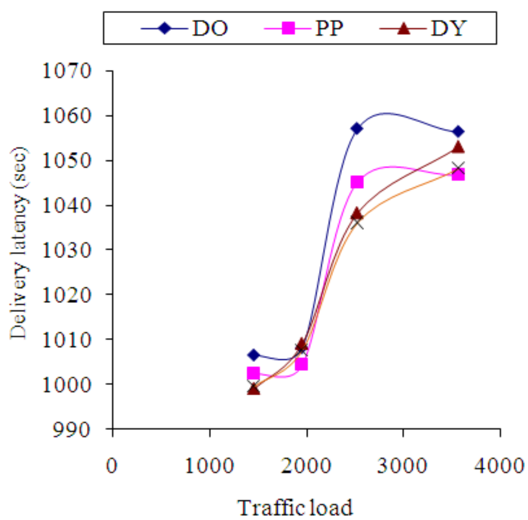

Fig. 3: Delivery latency Vs traffic load

The new prioritized policy which combines the lifetime and the priority of the messages do not decrease the delivery ratio compared to DO policy but guarantees delivery of high priority messages first. The rationale behind the result is that the messages with high priority are forwarded first. So they have more chances of earliest delivery than other messages. This ensures that the high prioritized message is forwarded with least delay and least likelihood of being dropped due to buffer overflow. This improvement of the performance of high priority messages at a little overhead of maintaining and processing the index table gives a special merit to the proposed approach.

Simulation results for different dropping policies with FCFS as the scheduling policy with respect to delivery latency are shown in the Fig 3. It can be observed from the result that as and when the traffic load increases, the delivery latency increases rapidly irrespective of the policies. At the same time, it also ensures that the delivery latency does not get increased upon incorporating the proposed approach when compared to other policies due to increase in overhead. But the proposed policy guarantees the delivery of high priority messages with least delay which is confirmed through the results of simulation

DISCUSSION

The system is further evaluated to check the performance behavior of messages with different priorities at different rate of generation and discussed in this section. The result shown is average of several simulation runs. The scenario 1 is the case when there is no overflow. The scenario 2 and 3 are the case when there is an overflow.

Scenario 1(messages with different priorities at equal rate): In scenario 1, messages with different priorities are generated at equal rate and their delivery ratio is observed. The result in the graph of Fig. 4 confirms that the delivery ratio of high priority messages is higher than normal messages. This is because according to the proposed policy, all high priority messages are scheduled first. Therefore almost all messages with high priority reach their destination before the lifetime expires.

Scenario 2 (messages with different priorities at different rates): In scenario 2, messages are generated such that rate of high priority messages is more than the rate of normal messages (i.e., high priority messages are doubled that of normal messages). When the load of high priority messages is increased, the delivery ratio of normal messages gets decreased. It can be observed in the result of Fig. 5. The rationale behind this result is that overflow occurs due to increase in load of high priority messages. But only normal messages are dropped to give room for high priority messages. Therefore the delivery ratio of high priority messages is not affected but delivery ratio of normal messages is affected due to loss.

Scenario 3 (messages with different priorities at different rates): In scenario 3, messages are generated such that rate of high priority messages is less than normal messages (i.e., high priority messages are halved that of normal messages).

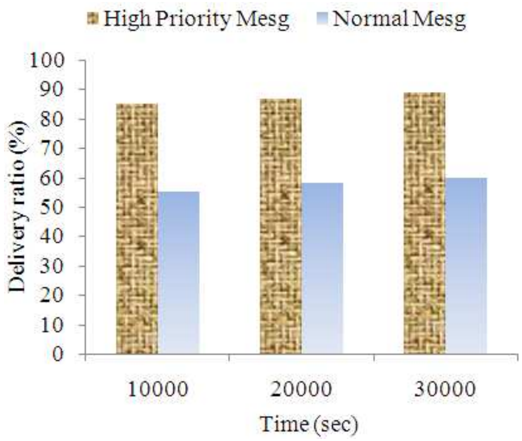

Fig. 4: Delivery ratio of messages with different priority at scenario-1

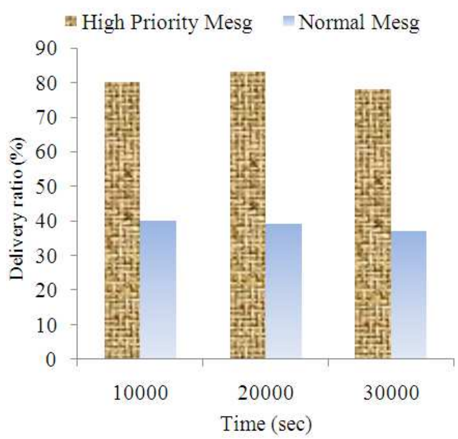

Fig. 5: Delivery ratio of messages with different priority at scenario -2

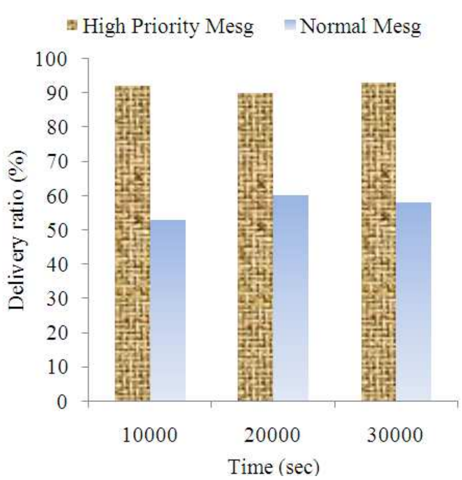

Fig. 6: Delivery ratio of messages with different priority at scenario -3

Even when there is increase in traffic load of normal messages, still the delivery ratio of high priority messages is higher. The rationale behind this result is that, as high priority messages are less, the overflow is only due to normal messages. In this scenario according to the policy, only normal messages with highest index are dropped to give room for normal messages with lesser index. Therefore the delivery probability of high priority messages is not affected as there is no loss of high priority messages and this can be inferred from the result in Fig. 6.

CONCLUSION

The study targets on application that requires preferential delivery in an environment where resources like buffer and bandwidth are constrained. The buffer management approach presented in this study indexes the traffic based on priority and lifetime and does scheduling and dropping based on their indexes. Thereby it ensures the delivery of high priority messages first. The results illustrate that the proposed buffer management policy performs equally well or more to other policies in terms of delivery ratio when there is no knowledge about the network is known and the resources are limited. The service required can be specified by the application. So it can be used in vehicular networks where several messages from different application can be transmitted with varied importance. In order to avoid starvation of normal messages, aging can be used. The fair queuing with dynamically assigned weights, can be utilized for controlling the quality of service. Thereby it addresses the integration of QoS in the DTN framework providing a bound on performance metrics like delay or throughput. Apart from delivery ratio and the delivery delay, the other metrics like loss probability and power consumption can be taken into account for optimization

REFERENCES

Alan, D., D. Greene, C. Hauser, W. Irish and J. Larson *et al*., 1987. Epidemic algorithms for replicated database maintenance. Proceedings of the 6th ACM Symposium on Principles of Distributed Computing, (PDC'87), ACM, New York, pp: 1-12. DOI: 10.1145/41840.41841

Amir, K., C. Barakat, T. Spyropolous, 2008a. Optimal buffer management policies for delay tolerant networks. Proceedings of 5th Annual IEEE Communications Society Conference Sensor, Mesh and Ad Hoc Communications and Networks, June 16-20 IEEE Xplore Press San Francisco, CA., pp: 260-268. DOI: 10.1109/SAHCN.2008.40

Amir, K., C. Barakat, T. Spyropolous, 2008b. An optimal joint scheduling and drop policy for delay tolerant networks. Proceedings of the International Symposium World of Wireless, Mobile and Multimedia Networks, June 23-26, IEEE Xplore Press, Newport Beach, CA., pp: 1-6. DOI: 10.1109/WOWMOM.2008.4594889

Aruna, B., B. Neil, Levine and A. Venkataramani, 2007. DTN Routing as a resource allocation problem. Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications, (CATAPCC'07), ACM, New York, pp: 373-384. DOI: 10.1145/1282427.1282422

Basu, P. and T. Little, 2002. Networked parking spaces: Architecture and applications. Proceedings of the IEEE 56th Vehicular Technology Conference, Sep. 24-28, IEEE Xplore Press, USA., pp: 1153 - 1157. DOI: 10.1109/VETECF.2002.1040785

Burgess, J., B. Gallagher, D. Jensen and B.N. Levine, 2006. MaxProp: Routing for vehicle-based disruption-tolerant networks. Proceedings of 25th IEEE International Conference on Computer Communications , Apr. 23-29, IEEE Xplore Press, Barcelona, Spain, pp: 1-11. DOI: 10.1109/INFOCOM.2006.228

Clausen, T., P. Jacquet, C. Adjih, A. Laouiti and P. Minet *et al*., 2003. Optimized Link state Routing Protocol (OLSR). Institut National De Recherche En Informatique Et En Automatique.

Daly, E.M. and M. Haahr, 2010. The challenges of disconnected delay-tolerant manets. Elsev. Ad Hoc Netw. J., 8: 241-250. DOI: 10.1016/j.adhoc.2009.08.003

David, H. and P. Giaccone, 2009. Optimal Routing and Scheduling for Deterministic Delay Tolerant Networks. in Proceedings of the 6th International Conference on Wireless On-Demand Network Systems and Services, Feb. 2-4, IEEE Xplore Press Snowbird, UT, pp: 27-34 DOI: 10.1109/WONS.2009.4801844

Davids, A., A.H. Fagg and B. N. Levine, 2001. Wearable computers as packet transport mechanisms in highly-partitioned ad-hoc networks. Proceedings of the 5th International Symposium Wearable Computers, Oct. 08-09, IEEE Xplore Press, Zurich , Switzerland, pp: 141-148. DOI: 10.1109/ISWC.2001.962117

Jones, E.P.C.,L. Li, J.K. Schmidtke and P.A.S. Ward, 2007. Practical routing in delay-tolerant networks. IEEE Trans. Mob. Comput., 6: 943-959. DOI: 10.1109/TMC.2007.1016

Fall, K., 2007 A delay-tolerant network architecture for challenged internets. Proceedings of the 2003 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications, (ATAPCC'03), ACM, New York, pp: 27-34. DOI: 10.1145/863955.863960

Farrell, S., V. Cahill, D. Geraghty, I. Humpreys and P. McDonald, 2006. When TCP Breaks: Delay- and Disruption- Tolerant Networking. IEEE Internet. Comput., 10: 72-78. DOI: 10.1109/MIC.2006.91

Fathima, G. and R.S.D. Wahidabanu, 2010a. A new queuing policy for delay tolerant networks. Int. J. Comput. Appli., 1: 52-55. DOI: 10.5120/422-622

Fathima, G. and R.S.D. Wahidabanu, 2010b. Comparison of DTN routing protocols and their buffer utilization using ONE Simulator.Govt. College of Engg, Salem, TamilNadu, India.

Geetha, J. and G. Gopinath, 2007. Ad hoc mobile wireless networks routing protocols-a review. J. Comput. Sci., 3: 574-582. DOI: 10.3844/jcssp.2007.574.582

Johnson, D.B. and D.A. Maltz, 1996. Dynamic source routing in ad hoc wireless networks. Mobile Comput., 353: 153-181. DOI: 10.1007/978-0-585-29603-6_5

Keranen, A., 2008. Opportunistic Network Environment Simulator. Helsinki University of Technology.

Ko, Y.B. and N. Vaidy, 2000. Location-Aided Routing (LAR) in mobile ad hoc networks. Wireless Network, 6: 307-321. DOI: 10.1023/A:1019106118419

Lee, S.J., W. Su and M. Gerla, 2001. Wireless ad hoc multicast routing with mobility prediction. Mobile Networks Appli. J.., 6: 351-360. DOI: 10.1023/A:1011478628358

Lindgren, A. and K.S. Phanse, 2006. Evaluation of queueing policies and forwarding strategies for routing in intermittently connected networks. Proceedings of 1st International Conference on Communication System Software and Middleware, (CSSM'06), IEEE Xplore Press, New Delhi, pp: 1-10. DOI: 10.1109/COMSWA.2006.1665196

Lindgren, A., A. Doria and O. Schelen, 2004. Probabilistic routing in intermittently connected networks. Assurance Partial Intermittent Resources, 3126: 239-254, DOI: 10.1007/978-3-540-27767-5_24.

Natsheh, E. and K. Buragga, 2010. Density based routing algorithm for spare/dense topologies in wireless mobile ad-hoc networks. Am. J. Eng. Applied Sci., 3: 312-319. DOI: 10.3844/ajeassp.2010.312.319

Pentland, A., R. Fletcher and A. Hasson, 2004. Daknet: Rethinking connectivity in developing nations. IEEE Comput., 37: 78-83. DOI: 10.1109/MC.2004.1260729

Perkins, C., E. Belding-Royer and S. Das, 2003. Ad hoc On-Demand Distance Vector (AODV) routing. . National Institute of Information Scholarly and Academic Information Navigator.

Ram, R., R. Hansen, P. Basu, R. Rosales-Hain and R. Krishnan, 2007. Prioritized epidemic routing for opportunistic networks. Proceedings of the 1st International MobiSys Workshop on Mobile Opportunistic Networking, (MON'07), ACM, New York, 62-66. DOI: 10.1145/1247694.1247707

Spyropoulos, T., 2005. Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks, Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking, (WDTN'05), ACM, New York, pp: 252-259. DOI: 10.1145/1080139.1080143

Spyropoulos, T., K. Psounis and C.S., Raghavendra, 2008. Efficient routing in intermittently connected mobile networks: The multi-copy case. IEEE/ACM Trans. Netw., 16: 63-76. DOI: 10.1109/TNET.2007.897964

Scott, K. and S. Burleigh, 2007. Bundle Protocol specification. Delay Tolerant Networking Research Group.

Vahdat, V. and D. Becker, 2000. Epidemic Routing for Partially Connected ad hoc networks. Duke University.

Zhang, Z., 2006. Routing in intermittently connected mobile ad hoc networks and delay tolerant networks: Overview and challenges. IEEE Commun. Surv. Tutorial., 8: 24-37. DOI: 10.1109/COMST.2006.323440