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MEASURING EFFICIENCY IN OPPORTUNISTIC AD HOC NETWORKS

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Opportunistic Networks are examples of wireless, ad hoc networks where there is an absence of a continuous end-to-end path. The proliferation of mobile device usage creates opportunities for nodes to forward packets in a dynamic way, utilizing nodes as they present themselves. In more conventional, static network infrastructures, it is typical to measure efficiency of message passing between nodes. We review approaches to the measurement of efficiency in networks, and propose a qualitative and quantitative metrics framework and simulation model that would be suitable for the evaluation of performance in opportunistic networks.

Keywords: Ad hoc network; MANET; opportunistic network; metric.

1. Introduction

The reduction in cost of wireless technologies is fostering an environment where computing and electronic communication is becoming increasingly pervasive. Cellular communications in particular have illustrated how the rapid uptake of portable communication devices has required significant investment in wired base stations that can propagate messages wirelessly. Whilst this approach is scalable to a point, the need for network infrastructure places demands for power to deliver messages over large geographical areas.

The advent of short range wireless communication is to some extent now facilitating message passing at a local level, and ad hoc architectures are one way of achieving this. Traditionally, wireless networks have made use of infrastructure to define a number of access points, between which routes can be established for packets to travel. In contrast, ad hoc networks do not possess such infrastructure and therefore need to self-configure in order that they can play the role of either an intermediary or an end-point. This configuration is performed dynamically, since nodes will join and leave the network without warning. If a node moves out of range, the ad hoc network must be able to accommodate the change, and this requires each ad hoc node to be able to contribute to a routing path as and when required. At any point in time the nodes in the network may be different, and it follows that the paths that packets travel varies also.

Mobile ad hoc Networks (MANET) are an example whereby the set of member nodes is regarded as particularly fluid. The proliferation of mobile devices that have networking capabilities has led to much interest in this research field. Typically, infrastructure based approaches to networks rely upon known, relatively static paths, and thus any established means of managing and measuring network performance is somewhat restricted when the infrastructure is absent.

Node mobility within a MANET therefore presents challenges for routing messages when a desired end-point moves out of wireless reception range. One approach is to utilize the inherent mobility of the nodes, to carry packets between nodes that are presently out of reach. For example, Figure 1 (adapted from[1]) illustrates the case where Node *A* needs to find a path to node *E*, even though it is out of range. Node *A* then transmits its message to those nodes that are within wireless range, Nodes *B* and *C*.

At some future time, the mobile nodes are physically in different positions (Figure 2). Node *B* is now within the wireless range of Node *E*, the destination node of the message that originated from Node *A*. Node *B* can now establish a route to Node *E* using Node *D*, and thus the message is delivered as originally intended.

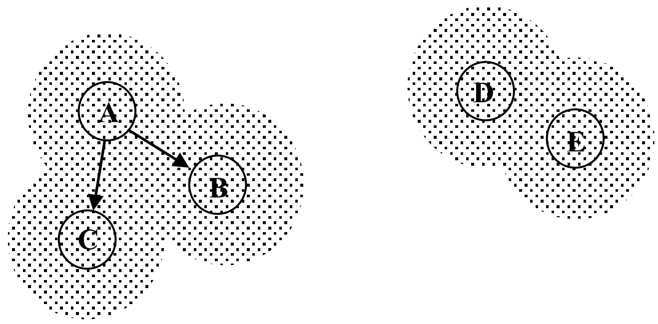

Figure 1. No continuous path between Node A and Node E.

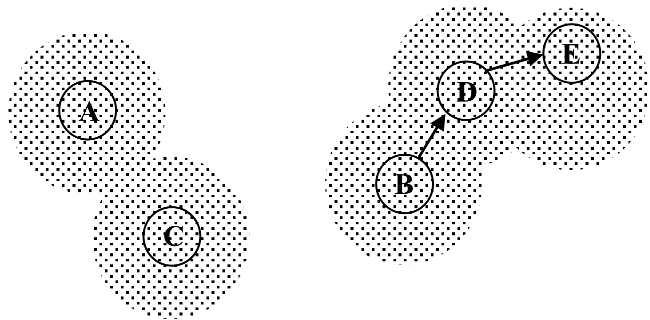

Figure 2. Message received by Node B is propagated to Node E via Node D.

The use of a node's mobility to establish network paths is referred to as *opportunistic networking*. In its most simple form opportunistic networking might take the approach of continuously broadcasting messages, which would make wasteful demands upon power and create excessive network traffic. Thus one of the objectives of opportunistic network protocols is to balance the achievement of message delivery against resource utilization.

2. Protocols for Ad Hoc Mobile Networks

A common characteristic amongst the many protocols for ad hoc networks is that it is assumed that an end-to-end path exists. As described above, mobile ad hoc networks place greater demands upon message routing and therefore there is a requirement for a protocol that can function without a defined path.

Vahdat and Becker[1] recognized this and identified the following assumptions for their work:

(i) The originator of a message is never within range of a base station;
(ii) The originator of a message does not know the location of the destination node, nor is it aware of a route to the destination;
(iii) The destination may be a roaming wireless host, and;
(iv) Pairs of hosts (not necessarily the originator and destination node) periodically come into close proximity through node mobility.

Specifically, the aims of a MANET should be to maximize message delivery success whilst minimizing power consumption. Considerable work exists that explores Quality of Service (QoS)[2,3] and power consumption[4,5] in ad hoc networks. Epidemic Routing[1] utilizes an epidemic algorithm devised for databases[6] to create a protocol that ignores any contextual information. Packets are forwarded to nodes by 'infecting' other nodes; the message is therefore propagated by 'carriers', whose mobility is exploited every time they come into range of a new node.

Conceptually at least, Epidemic Routing appears to achieve the scenario described in Figures 1 and 2, albeit at the potential expense of network resources. As an attempt to reduce demands on network resources, the protocol places constraints upon message hop count and per-node buffer space. The simulation results indicate high success rates for message delivery, though this effectiveness is rather expensive in terms of network resource consumption. As such, a hybrid approach of more traditional end-to-end routing is suggested, falling back to Epidemic Routing where defined paths are not available.

In contrast to Epidemic Routing, where the contextual information relating to a node is ignored, *probabilistic routing* assumes that the mobility of nodes is not random and that mobility exists to fulfill a particular purpose. If it is assumed that nodes have behavioral patterns, then it follows that probabilities can be assigned to the likely set of nodes that a particular node may connect with in the future.

The Probabilistic Routing Protocol using History of Encounters and Transitivity (PROPHET)[7] is an attempt to address the challenges of intermittent connections in mobile networks, without incurring the resource overhead of Epidemic Routing. PROPHET utilizes a relatively simple forwarding strategy in that a message is still propagated to another node, but only if the probability that the message will be successfully delivered is higher than the propagating node. The probability increases as a result of successful propagation, but also decreases as a function of time during periods of non-connectivity.

Hui et al[8] propose the creation of a context that is formed from the collection of nodes that constitute a community. The interactions between nodes in a community enables each node to be 'socially ranked', reflecting the portion of the community that it most actively engages with. Messages are then passed between nodes of the same community. For new nodes that are not identified as part of the same community, if the social ranking is higher than that of the sender, the message is transferred. However, the reliance upon contextual information does create challenges when the contextual information is not present; as a result higher resource utilization returns and poor Quality of Service is exhibited by such protocols[9].

3. Appropriate Metrics for MANETs

Measurement is an important aspect of both the design and management of communication networks. The measures that are taken are used to inform the design of new networks, whilst also providing the basis for interventions during the management of an operating network. Different network configurations can give predictable and unpredictable results, and such data is used as the basis of design-time or run-time optimization.

As described earlier, MANETs have fluid routing paths as a defining characteristic, that presents challenges for their management over more conventional, infrastructure based architectures. Whilst we expect MANETs to behave differently, it is useful to understand the metrics that reflect common characteristics that present themselves in MANETs.

Recognizing that Epidemic Routing achieves excellent performance with unlimited resources, Probabilistic Routing establishes constraints to approach the challenge in a more pragmatic way. Whilst mobile device technology is advancing quickly, there are still situations where nodes need to minimize resources, such as remote sensor networks[10,11]. Lin[12] has also established that memory and time are critical resources that limit scalability in ad hoc networks. A number of potential metrics have been proposed for the measurement of network performance. Rangarajan & Garcia-Luna-Aceves[13] identify the following:

(i) Delivery Ratio – the ratio of packets delivered to packets sent, on a per-pair basis;
(ii) Latency – the total delay incurred for packets travelling a path from end-to-end;
(iii) Network Load – the ratio of data packets received, to number of control packets;
(iv) Number of Hops – the ratio of number of hops travelled, to number of packets received. This measurement is an indicator of routing accuracy.

Niazi[14] adopts a different set of metrics:

(i) *Number of hops* – this is used as an abstract indicator of latency; the greater the number of hops, the further the packet has travelled and the greater the delay;
(ii) *Number of leftover queries* – the total number of unsuccessful queries as a result of an incomplete path.
(iii) *Number of messages per node* – the average number of search messages that a node has to forward or process. This is an indicator of power demand.
(iv) *Number of peak messages* – the peak loading of messages for a node in the network.

These measures are focused upon content delivery in that there is an emphasis upon query performance and latency. Notably latency is inferred from the total number of hops.

Song & Kotz[15] consider the following:

(i) *Delivery Ratio* – the ratio of messages delivered to messages generated;
(ii) *Delay* – the time taken between message generation and delivery;
(iii) *Message Transmission* – the total number of messages delivered across all nodes;
(iv) *Meta-data Transmission* – the total number of meta-data packets delivered across all nodes;
(v) *Message Duplication* – the number of times a message was replicated;
(vi) *Storage Usage* – the amount of storage (maximum and mean) utilized across all nodes.

The work of Baldoni et al[16] assumes a more abstract position. They consider only *delivery* and *overhead*. *Delivery* indicates the number of subscribers who receive a message as opposed to those subscribers who are interested in the message. *Overhead* is the total number of link layers generated for each delivery. Similarly, Liu & Sailhan[17] take a simple approach to measurement by quantifying, (1) traffic generated in the network as a result of message forwarding, and (2) traffic generated by the node requiring the service.

Normally the following metrics would be monitored for a wired network: throughput, response time, access time, availability, reliability, bandwidth, utilization, error rate, peak load, average load and system cost. In relation to MANETs, metrics related to availability, reliability, bandwidth, utilization and error rate, are mostly not applicable.

However, for the purposes of comparison with more established or benchmark network architectures it would be useful to consider *bandwidth, utilization* and *error rate*, since these will give an indication of effectiveness. Specifically, *bandwidth* indicates the maximum throughput of a network or path. *Utilization* is a measure of the system resources that are consumed by passing traffic. *Error rate* quantifies the proportion of errors that occur during transmission. Table 1 summarizes the candidate metrics that have potential for describing the performance of an opportunistic MANET architecture.

Metric	Description
Delivery Ratio	Ratio of messages delivered to messages generated [17].
Latency	Delay measured for packets travelling end-to-end across the network [14].
Network Load	Maximum number of messages that busiest node in the network passes [13].
Number of Hops	Number of hops taken by a packet from the originator to the destination.
Messages per Node	Average number of messages passed by each node [13].
Peak Messages	Maximum number of messages that busiest node in the network passes [13].
Message Duplication	Number of times a message was copied [17].
Storage Usage	Total amount of storage used across all nodes [17].
Bandwidth	Maximum possible through put of the network.
Utilization	Ratio of current network traffic to the maximum traffic.
Error Rate	Ratio of packets with errors received to the total number of packets received.

Table 1. Potential metrics for opportunistic MANETs.

Message generation and subsequent propagation has an impact upon the resources consumed, in terms of storage cost, network bandwidth and, perhaps most crucially for mobile devices, an associated power cost. There may also be infrastructure costs such as monetary charges made by private network providers. This may provide further constraints upon the transmission that can be afforded. Bearing these metrics in mind, a node may choose to manage its operational costs by deleting messages (to save storage) or to reduce transmission activity (to conserve power). Whilst an individual node may only be interested in its own properties, there is also the holistic perspective that is of interest to network designers and managers.

The *Peak Messages* metric indicates the peak demand placed upon a network. Such is the transient nature of a MANET, this will be of particular interest since both the peak load, and the peak load carrying capability of the network, will constantly be in a state of flux. For instance, if Epidemic Routing is utilized, we can expect greater demands placed upon the available resources, with a likely failure of the network due to saturation with duplicated messages[1].

Protocol types that rely upon flooding (such as Epidemic Routing and Probabilistic Routing) inherently are exposing messages to more nodes than the sender may desire. If the information is sensitive then the message can be encrypted, but the addition of routing information with respect to where a packet has been, would enable a model of trust to be developed[1]. The inclusion of this information can also assist receivers who may choose to maintain a list of trusted providers, automatically rejecting packets from parties that are not trusted.

3.1. *Efficient Provisioning*

So far we have considered the characteristics of MANETs and discussed a range of metrics that may be relevant. For the purposes of this research, we have identified a collection of metrics that can be used to evaluate the relative efficiency of a particular MANET. In order to achieve this, it is necessary to identify the measures of a MANET that can be used to compare with established benchmarks.

As such we propose the following metrics: *Network Load; Delivery Ratio; Latency; Number of Hops; Power Usage; Peak Messages; Error Rate* and *Duplication*. The subsequent sections will now explore the use of these measures in relation to two benchmark protocols, Epidemic Routing and Probabilistic Routing.

4. An Assessment Framework for Efficient Provisioning

In order to assess the efficiency of opportunistic network provision, we describe an overall qualitative measure that is composed of a number of quantifiable measures. Should a particular protocol be deemed 'efficient', we would expect that a protocol can reliably and accurately route a message first time, with minimal impact upon the network resources or its users. In the context of an opportunistic network case study, we have taken a two stage approach; firstly we illustrate the application of qualitative metrics to the case study to explore particular characteristics of the different routing protocols. Secondly, through the use of a simulation study, we demonstrate the use of metrics to quantify observable differences between the Epidemic and PRoPHET routing protocols.

4.1. *A Case Study*

A town centre shopping mall contains a base network infrastructure of Wi-Fi routers configured to work in ad hoc mode, which are sited in a number of locations. As a user enters a location with a mobile device, they join the network. Advertisements for services and applications are now downloaded to the user's mobile device. Applications that are either resident upon the user's device, or are accessible Cloud applications, filter the adverts in relation to a user's particular profile. Service providers, such as shop keepers, restaurateurs, etc., create adverts for new services and offers. These adverts propagate through the network to each mobile device that is currently connected. As a user leaves a location, there may be messages or adverts that will remain associated with the user. These associations will be trigger new events by subsequent connections to ad hoc *networks in other locations. In this way an originator in one location, having identified that a significant amount of custom comes from another location, could target that location. For example, a chain of retail outlets could propagate a voucher that is redeemable in any one of the bricks and mortar stores. These Wi-Fi hotspots are not connected to each other, and there is no central infrastructure except for the Wi-Fi system. The propagation of these adverts between hotspots is achieved through the mobility of users; it is the mobility of users that connect the hotspots, in an ad-hoc fashion.*

4.2. *Qualitative Analysis*

By applying the framework of metrics to this scenario, with a focus on targeting mobility between geographical locations, we can explore the relative indicative performance of a given protocol. Table 2 summarizes the initial results in relation to Epidemic Routing and Probabilistic Routing. We have identified that the qualitative assessment of each one of the characteristics serves to differentiate between the two benchmark protocols selected. Notably the error rate characteristic is assumed to be the same for each case, at least conceptually, since this is an indication of the quality of the wireless channel, and is therefore an environmental factor.

Metric	Benchmark	Epidemic Routing	Probabilistic Routing (PRoPHET)
Network Load	Low	High	Low
Delivery Ratio	High	Very High (100%)	High
Latency	Low	Mid (1)	Low
Number of Hops	Low	Mid (2)	Low
Power Usage	Low	High (3)	Low
Peak Messages	Low	Very High	Med
Error Rate	Low	Low	Low
Duplication	Low	Very High	Low

Table 2. Comparison of Epidemic Routing and Probabilistic Routing in relation to benchmark metrics identified for the efficient provisioning of opportunistic networks.

Notes:

(1). Latency is affected by the time taken before an infected node leaves the first location.
(2). Number of hops depends upon the number of hops needed to locate a suitable carrier.
(3). Power usage is high because of the total number of nodes carrying the message.

4.3. *Simulation Study*

Using the chosen protocols in 'The ONE' (Opportunistic Network Environment) simulator[18], a small scenario of 230 randomly moving nodes in an area of 4500 by 3400 units was created. Of these nodes, 10% were enabled to follow a path to a defined point of interest at random times. A group of 4 nodes generates messages for the point of interest at random intervals between 25 and 35 seconds. The communication range was defined as 100. The results are presented in Table 3.

Metric	Epidemic	PRoPHET
Messages Injected	1461	1461
Peak Messages	81496	69425
Messages Delivered	353	402
Probability of Delivery	0.24	0.28
Overhead Ratio	142	98
Mean Delay	4163	3969
Number of Hops	4	3

Table 3. Simulation results for the comparison of Epidemic and PRoPHET routing.

5. Discussion

A key objective of this work is to provide a holistic assessment as to the potential efficiency of any routing method for opportunistic networks. Such an assessment will assist network designers who need to consider important characteristics when creating a bespoke protocol. Similarly, the ability to compare existing protocols in terms of their relative performance for MANETs will inform the strategy for implementing compound protocols. For instance, a MANET may operate with a satisfactory QoS if there is adequate coverage provided from base stations that are operating in ad hoc mode. Once the mobile nodes start operating at the fringe of the coverage, the conditions present for opportunistic routing might become apparent. Since we would expect *Delivery Ratio* to be maximized as a general property of any type of network, we would also want to minimize *Power Usage* and *Peak Messages*. A suitable approach in this instance would be to prioritize an ad hoc protocol, which is substituted for Epidemic Routing or Probabilistic Routing as mobility increases and QoS starts to decline. Furthermore, the Network Manager may choose also to optimize the protocol to satisfy specific conditions that are present; a sensor network may place an emphasis upon power conservation and sacrifice *Delivery Ratio*. Alternatively, successful message delivery may be more desirable, even at the expense of *Message Duplication* and *Power Usage*.

This comparison of different routing protocols relies upon relative values for the framework to be effective. Network designers will find the framework useful for making informed judgments during the protocol design stage, particularly with regard to understanding the likely impact of a protocol on a particular network. Predictions about network load will provide an indication of the demands to be made of the network, whilst power usage will suggest the load that each node will be able to bear. This insight into the implementation characteristics will enable more focused decisions to be taken with regard to protocol optimization at earlier stages of the design process. Additionally, the framework assists the identification of parameters for the purposes of network management. The quality of the network is suggested by the *Error Rate* metric. A holistic assessment of *Delivery Ratio*, *Latency*, *Number of Hops* and *Message Duplication* will demonstrate the ability of the routing algorithm.

The ability to enrich the analysis stage of protocol design for opportunistic networks will also facilitate the incorporation of characteristics that influence the behavior of the network during operation. For instance, a designer may wish to maximize *Delivery Ratio* in a sensor network, yet without the compromise that a low *Power Usage* protocol might enforce. This desire may lead the designer to attempt to influence the nodes during network operation, by providing incentives for nodes to stay in proximity to other nodes that have a good success rate for message delivery[19]. Cooperation is a mechanism that can often deliver results that move towards a more optimal state. Again, the framework assists protocol design specification by enforcing consideration of the crucial characteristics, in a comparable way, at the earliest opportunity.

6. Conclusions and Further Work

In summary, we have considered the characteristics of MANETs, and in particular, the need for opportunistic routing when end-to-end paths become absent or are intermittently available. In such cases, the network protocol can be engineered to embrace the mobility of nodes, so that packets can be passed from one area of network coverage to another, between nodes that opportunistically come into close enough proximity to each other for a message exchange to take place. The lack of a defined end-to-end path does create a challenge however, rendering conventional approaches to the measurement of efficient network provision inadequate. Therefore it is difficult to compare opportunistic protocols, not only between each variant, but also with respect to more traditional, benchmark network protocols and architectures.

Initial results from the simulation study indicate that the framework has the potential to identify crucial aspects pertaining to disparate protocols. In the case of the direct comparison between the two protocols, PRoPHET does indeed demonstrate measurably better performance over Epidemic Routing. Whilst the body of literature indicates that this should be the case, it underlines the potential of the framework for the useful assessment of opportunistic network efficiency.

We anticipate that further work will enable patterns in mobility to be identified, which is of particular interest to our research. The simulator will then be required to model mobility patterns, which will augment the existing model with additional characteristics. The adaptation of a Markov chain is one such approach to explore[20].

We have reviewed two benchmark protocols, *Epidemic Routing* and *PRoPHET Routing*, and derived a robust set of assessment metrics for the assessment of opportunistic ad hoc networks. These metrics serve as a framework for the analysis and evaluation of new and existing protocols that also improves the process of protocol optimization. The application of this framework to the two benchmark protocols above, through both a qualitative and quantitative simulation study, indicates the relative comparison that can be made between pertinent protocol design characteristics.

References

1. Vahdat, A. & Becker, D., "Epidemic routing for partially connected ad-hoc networks". Technical Report CS-200006, Duke University, 2000.
2. Lee, S.B., Ahn, G., Zhang, X., and Campbell, A.T., "INSIGNIA: An IP-Based Quality of Service Framework for Mobile and ad Hoc Networks". In Journal of Parallel and Distributed Computing, 60, pp. 374-406, 2000.
3. Sinha, P., Sivakumar, R., Bharghavan, V., "MCEDAR: Multicast Core-Extraction Distributed Ad hoc Routing". In Proceedings of IEEE Wireless Communications and Networking Conference, September 1999.
4. Bhagwat, P., Bisdikian, C., Korpeoglu, I., Naghshineh, M., and Tripathi, S., "Design Issues for Low-power, Low-Cost, Short Range Wireless Networking". In IEEE International Conference on Personal Wireless Communications (ICPWC99), 1999.
5. Singh, S., Woo, M., "Power-Aware Routing in Mobile Ad Hoc Networks". In Proc. of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking, pp. 181-190, 1998.
6. Demers, A., Greene, D., Hauser, C., Irish, W., Larson, J., Shenker, S., Sturgis, H., Swinehart, D., and Terry, D., "Epidemic Algorithms for Replicated Database Maintenance". In Proceedings of the Sixth Symposium on Principles of Distributed Computing, pp. 1-12, 1987.

7. Lindgren, A., Doria, A., and Scheln, O., “Probabilistic routing in intermittently connected networks”. In Proc. of the Fourth ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc 2003) 2003.
8. Hui, P., Crowcroft, J., & Yoneki, E., BUBBLE Rap: Social-based Forwarding in Delay Tolerant Networks, In Proceedings of the 2nd ACM International Workshop on Mobility in the Evolving Internet Architecture (MobiArch 2007), 2007.
9. Verma, A. & Srivastava, A., “Integrated Routing Protocol for Opportunistic Networks”, International Journal of Advanced Computer Science and Applications, Vol. 2, No.3, 2011.
10. Estrin, D., Govindan, R., Heidemann, J., and Kumar, S., “Next Century Challenges: Scalable Coordination in Sensor Networks”. In Proc. of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking, pp. 263-270, 1999.
11. Heinzelmann, W.R., Kulik, J., and Balakrishnan, H., “Adaptive Protocols for Information Dissemination in Wireless Sensor Networks”. In Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking, pp. 174-185, 1999.
12. Lin, C., “AODV Routing Implementation for Scalable Wireless Ad-Hoc Network Simulation”, Technical Report, 040421-swans-adov, Cornell university, April 2004.
13. Rangarajan, H., & Garcia-Luna-Aceves, J.J., “Using Labeled Paths for Loopfree On Demand Routing in Ad Hoc Networks”. In Proc. of Mobile Ad Hoc Networking and Computing - MobiHoc , pp. 43-54, 2004.
14. Niazi, M., “Self-organized Customized Content Delivery Architecture For Ambient Assisted Environments”. In Proc. of the third international workshop on Use of P2P, grid and agents for the development of content networks (UPGRADE '08), 2008.
15. Song, L., & Kotz, D. F., “Evaluating Opportunistic Routing Protocols with Large Realistic Contact Traces”. In Proc. ACM 2nd Workshop on Challenged Networks (CHANTS .07), pp 35–42, 2007.
16. Baldoni R., Beraldi R., Querzoni L., Cugola G., Migliavacca M., "Content-based routing in highly dynamic mobile ad hoc networks", International Journal of Pervasive Computing and Communications, Vol. 1 Iss: 4, pp.277 – 288, 2005.

17. Liu J., & Sailhan, F., “Group Management for Mobile Ad Hoc Networks: Design, Implementation and Experiment”, In Proc. of the 6th international conference on Mobile data management, 2005.
18. Keränen, A., Ott, J., Kärkkäinen, T., “The ONE simulator for DTN protocol evaluation”, SIMUTools '09: Proceedings of the 2nd International Conference on Simulation Tools and Techniques, Rome, Italy, ICST New York, NY USA. ISBN 978-963-9799-45-5, 2009.
19. Buttyan L., Dora L., Felegyhazi M., Vajda I., Barter Trade Improves Message Delivery in Opportunistic Networks, Elsevier Ad Hoc Networks, vol. 8, no. 1, pp. 1-14, 2010.
20. Niu, J., Guo, J., Cai, Q., Sadeh, N., Guo, S., "Predict and spread: An efficient routing algorithm for opportunistic networking," Wireless Communications and Networking Conference (WCNC), 2011 IEEE , vol., no., pp.498-503, 28-31 March 2011.