

# Towards a framework for the evaluation of efficient provisioning in opportunistic ad-hoc networks

Anthony Smith and Richard Hill  
Distributed and Intelligent Systems research Group  
University of derby  
Derby, UK  
{a.k.smith, r.hill}@derby.ac.uk

**Abstract**— In wireless ad-hoc networks where there is no continuous end-to-end path we move into the area of opportunistic networks. Forwarding messages via any encountered nodes, such as the mobile devices that many users already carry. Normally we are looking for the most efficient method of passing these messages across the network, but how do we evaluate the different methods. We propose to develop a framework that will allow us to evaluate how efficiently provisioning has been performed. This has been explored with the use of a case study and two benchmark protocols, Epidemic and PROPHET. We present the results of this analysis and describe an approach to the validation of this through simulation.

**Keywords**— *Ad Hoc Networks; MANETs; Opportunistic Networks; measurement; routing; simulation.*

## I. INTRODUCTION

Typically, wireless networks that are infrastructure-based, make use of multiple nodes (access points) to define paths through which packets can travel. In contrast, an ad-hoc network is a collection of autonomous nodes that communicate wirelessly without any pre-existing infrastructure. They are able to configure themselves dynamically without any external intervention. The nodes can act as both end systems and intermediary systems to forward packets to other nodes. As a consequence, they are able to take the form of a multi-hop wireless network, allowing for end-point to end-point communication even when those nodes are out of wireless range. The actual path the packets take can vary as nodes become available. In a mobile ad-hoc network (MANET), this constant changing of the path occurs as nodes come into, and move out of range. It is the fluidity of the path that distinguishes MANET networks from ‘standard’ wired network or infrastructure based wireless networks, which tend to prohibit direct node-to-node communication.

In an ad-hoc network, a node may move beyond the range of all other nodes, breaking any existing communication path. One solution is to make use of passing nodes that are moving in the correct direction to carry messages to the out-of-range node. This method is referred to as opportunistic routing, which is the basis of opportunistic networking. Opportunistic networks utilize a store-carry-and-forward paradigm. The objective is to move the message as quickly as possible whilst minimizing any load on the network itself. If the taking, carrying and forwarding of

packets demands significant or excessive resources, then the messages will not be carried.

For example, a group of vehicles may establish an ad-hoc network that provides a potential path between those at the front and those at the rear of the group. Since the group is composed of mobile, autonomous entities, it is feasible that one or more of the group may become separated from the network, breaking any communication paths that have been established between particular nodes.

However, a passing vehicle travelling in the opposite direction could exploit the opportunity to carry a communication packet between the front group to the rear group of vehicles. Similarly, a vehicle travelling in the same direction but faster than either group could also be used to carry packets from the rear group to the front group.

The combination of opportunistic network architectures and the increased proliferation of network devices such as mobile phones, presents the ability to exploit an increasing number of existing and emerging domains. One such domain is that of social networking, where the physical proximity of nodes can add new dimensions to how interactions are solicited and engaged with.

## Ad-hoc Network Protocols

There have been a significant number of protocols created to support ad-hoc networks, but all require an effective end-to-end path. In opportunistic networks, the lack of a defined end-to-end path has required the development of different protocols. Epidemic routing [11] is one such protocol, and is context oblivious. Epidemic or infection routing is based on a flooding scheme whereby a node with a message, forwards that message to all nodes that it meets while in motion. This continues until a specified number of hops is achieved or the message lifetime expires. This protocol is effective in that it achieves node coverage with low latency; however, it is less efficient from the level of network load that is created. Not only is the message forwarded to every node in the area, but nodes that have already received the message will continue to be forwarded to. Not only does it cause congestion but it is also a wasteful consumer of other resources, such as bandwidth, storage, and power.

Whereas Epidemic is context-oblivious, that is it uses no context information in forwarding to nodes, other protocols are context-aware. Such an example is the Probabilistic Routing Protocol using History of Encounters and

Transitivity, PROPHET [6]. This protocol makes the assumption that the movement of nodes is not random and that there is a reason behind their movements. Every node is assigned a probability that it will come into contact with a certain node; the probability increases when it connects with that node and reduces as a function of time otherwise. When nodes connect they swap the predictabilities of the message destinations they carry. The message is passed only if the passing node has a higher probability of delivering it. An alternative to this is Bubble Rap [3] which is a social network protocol. This is a context based system where the context is the social community the users are part of. Communities are defined by the pattern of contacts between nodes, which are ranked on their sociability, a measure that is based on the nodes they are usually in contact with. When a message is sent the protocol looks for nodes of the same community. If a node carrying the message comes into contact with a node of the same community as the destination, the message is passed. Alternatively, if the new node is not in the same community, but has higher ranking than the current node, the message will be passed. Verma & Srivastava [12] identified that context-aware protocols have limitations when the context information is not available, causing a high overhead, extended message delay and poor delivery.

## II. ISSUES

In all networks measurements are taken in order to give an indication as to how the network is operating. Measurement provides a basis upon which different configurations can be compared or to indicate the effects of optimization. By their very nature, ad-hoc networks and opportunistic networks will perform differently than wired or infrastructure based networks. For instance in ad-hoc networks the path will vary, and in opportunistic networks there will be no fixed path at all. In order to understand the impact of such networks it is necessary to reflect the important characteristics that appropriate metrics should take account of.

Lin [5] identifies that memory and times are the critical resources that limit scalability in an ad-hoc network, evidenced by simulations that consider memory usage and elapsed time in relation to the number of nodes in a network. Rangarajan & GarciaLunaAceves [9] consider four metrics: delivery ratio, latency, network load and number of hops. Delivery ratio is defined as the ratio of packets delivered to those sent on a per pair basis. Latency is defined as the measured delay for packets travelling end-to-end across the network. Network load is defined as the ratio of the number of data packets received to the number of control packets, and hops is the ratio of the number of hops travelled by each packet to the number of received packets. The hops metric in particular, gives an indication of the accuracy of the routing in the network. Liu & Sailhan [7] in their paper measured the traffic in the network that occurred due to message forwarding and the traffic that was generated by the node requiring the service.

Niazi [8] utilizes four metrics as follows: 1) hops, 2) leftover queries, 3) messages per node and 4) peak messages. These are focused upon an assessment of content delivery which is of potential interest for this work. In this case hops are defined as the number of hops a successful search has to travel before it is returned to the initiator. This is effectively a measure of latency based on the delay in finding the required resource. For 2), leftover queries are those queries that were unable to reach the destination node. Messages per node (3) is the effective overhead, as in the average number of messages passed by each node. This is an indication of resource usage in that the passing of each message incurs a 'cost' in terms of power used. Metric 4), Peak messages, is defined as the maximum number of messages that the busiest node in the network would pass. Song & Kotz [10] identified six metrics for consideration: 1) delivery ratio, 2) delay, 3) message transmission, 4) meta-data transmission, 5) message duplication and finally 6) storage usage. Their definition of delivery ratio was a ratio of messages delivered to messages generated, whereas the definition of delay was the time taken between generation and delivery of a message. Message transmission is the total number of messages across all nodes, and meta-data transmission is the total number of meta-data packets across all nodes. Message duplication is defined as the number of times a message was copied, and storage usage as the amount of storage utilized across all nodes. Baldoni et al [1] describe the key metrics as being delivery and overhead. They defined delivery as the ratio of the number of subscribers who received a message to the number of subscribers interested in the message. Overhead is the number of link layer packets produced for each delivery.

Typically, for a 'normal' wired network, the following metrics would be measured; throughput, response time, access time, availability, reliability, bandwidth, utilization, error rate, peak load, average load and system cost. The areas not covered above are; availability, reliability, bandwidth, utilization and error rate. Most are not applicable to MANETs; however bandwidth, utilization and error rate would appear to be useful metrics when looking at effectiveness, or when comparing performance with benchmark network architectures. Bandwidth will provide a measure of the maximum possible throughput of a network or communication path, and utilization is a measure of the systems resources that are used by the passing traffic. Error rate shows the degree of errors encountered during transmission.

To summarize so far, we consider the following as potential metrics for MANETs:

- Delivery ratio. A ratio of messages delivered to messages generated [10].
- Latency. The delay measured for packets travelling end-to-end across the network [9].
- Network load. The maximum number of messages that busiest node in the network passes [8].
- Number of hops. The number of hops taken by a packet from the originator to the destination.

- Messages per node. The average number of messages passed by each node [8].
- Peak messages. The maximum number of messages that busiest node in the network passes [8].
- Message duplication. The number of times a message was copied [10].
- Storage usage. The amount of storage used across all nodes [10].
- Bandwidth. The maximum possible throughput of the network.
- Utilization. The ratio of current network traffic to the maximum traffic.
- Error rate. The ratio of packets with errors received to the total number of packets received.

Clearly, the transmission of a message has resource implications for both the device and the network. For every message there is a storage and power cost incurred from its reception and subsequent re-transmission. It should be noted that there could also be a direct cost associated with the use of the wireless media, such as service provider charges. This will result in limitations as to how many messages can be carried by the node. If the power usage to transport a message is too high for a node, the message will be deleted in order to conserve power. There are also implications for the network resources as a whole indicated by the Peak messages metric, as in the peak demand placed upon the network. It follows that high levels of message duplication, as in the case of the Epidemic protocol [11], will ultimately lead to network failure as the network becomes saturated with multiple copies of the message.

In a typical MANET scenario there are also a number of significant ethical considerations. Firstly, the carrier of the message could read the content and amend or copy it. This could be addressed by the use of encryption. However, this also prevents inspection to prevent the spread of malicious content. Secondly, the carrier could be holding software that allows remote access to their device. If the process needs to interrogate the nodes to identify a suitable carrier, it is feasible that other data could be extracted.

Alternatively if the interrogation process looks for mobility patterns, then that data might inform queries such as 'is the building unoccupied' or 'is person X in special location Y'. Such ethical considerations are pertinent to this field of research, and it is intended that these scenarios should provide the basis of subsequent evaluation of a potential framework.

#### Efficient Provisioning

For the purposes of this work, we consider efficient to be defined as: "functioning in the best possible manner with the least waste of time and effort".

To provide an assessment of the relative efficiency of a MANET, we therefore propose a means of systematically guiding the scrutiny of a particular network, with respect to established benchmarks.

To achieve this aim, a framework will need to identify measurable impact on both the network and also the various individual nodes contained within the network. Therefore, we propose the following characteristics:

- Delivery ratio
- Latency
- Network load
- Number of hops
- Peak messages
- Message duplications
- Storage usage
- Error rate

The subsequent sections will now explore some potential domain models before indicating how the framework can be used by considering two benchmark protocols.

### III. POTENTIAL MODELS OF DELIVERY

Opportunistic networks can support a number of delivery models. For instance, an extended MANET model might illustrate cooperating users who provide communications. Another model might be to envisage a collection of retail shopping outlets that wish to cooperate to advertise products and services. When a user comes into proximity of the collaborating outlets' network, focused adverts would be transmitted to each user's mobile device. This model of advertising services could also be used to promote other commercial services, or coupons/vouchers and tokens could be distributed in this way. Another model would be the passing of community based adverts, such as those for the local swap club. This community of practice method lends itself to a model based on tourists sharing information on tourist sites [2].

As mentioned earlier there is a cost associated with the transportation of a message. As a result, users are likely to require incentives to engage in a network that requires the community participation 'price' of message transportation. Buttyan et al [2] describe the concept of bartering, where resources are exchanged for mutual benefit. In this scenario, a user would willingly carry messages for the purposes of the network, in order to have access to messages that might be of direct value to the user. Other incentives can be used, such as direct payment or payment in kind. The issues that arise when payment is involved include: 1) ensuring the user has distributed the message, 2) accessing the funds of another, and 3) a method of arbitration for when an unintended outcome is reached. However, the concept of incentives is common to all models that rely on engagement.

### IV. TOWAEDS A FRAMEWORK

We therefore need to describe a framework that can guide the evaluation of the efficiency of message passing in opportunistic ad-hoc networks. For the purposes of assessing message passing efficiency we describe a qualitative assessment that balances across a number of quantifiable values. The likely characteristics of an efficient protocol would therefore allow the message to be routed accurately

first time with little impact on the network or users. The potential metrics to verify this are described in Table I.

TABLE I.

Metrics	VALUE
Network load	Low
Delivery ratio	High
Latency	Low
Number of hops	Low
Power usage	Low
Error rate	Low
Duplication	Low

### A Case Study

We shall now explicate the use of the framework by considering a simple case study. A town centre or 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. As a result of this, adverts for services and applications are 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 be 'triggered' 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. In the context of this we need to be both effective and efficient.

By applying the framework to this scenario, with a focus on the targeting mobility between locations, we can explore the relative indicative performance of a given protocol.

In the case of Epidemic routing, the results are summarized in Table II [2].

TABLE II. RESULTS OF EFFICIENT PROVISIONING FRAMEWORK IN RELATION TO THE EPIDEMIC PROTOCOL.

Metrics	VALUE
Network load	High
Delivery ratio	100%
Latency	Mid(1)
Number of hops	Mid(2)
Power usage	High(3)
Error rate	Low
Duplication	Very High

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 on the total number of nodes carrying the message.

An alternative comparison would be to use the PROPHET routing protocol. Table III illustrates the findings[6].

TABLE III. RESULTS OF EFFICIENT PROVISIONING FRAMEWORK IN RELATION TO THE PROPHET PROTOCOL.

Metrics	VALUE
Network load	Low
Delivery ratio	High
Latency	Low
Number of hops	Low
Power usage	Low
Error rate	Low
Duplication	Low

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.

## V. DISCUSSION

The objective of the framework is to provide a set of measurements that together allow us to holistically assess the efficiency of any method used to route messages in opportunistic networks. We anticipate that the framework may be applicable beyond the domain of opportunistic networks also.

Since it is the comparison between different routing protocols where the framework will used, absolute values will not be required. The measurements that are to be taken

will give an informed understanding of the impact of a routing protocol upon the network, particularly with regard to the utilization of network load and power usage. The network load will indicate the work the network has to done, while the power usage indicates the load that each individual node is able to carry. From this we shall then be pursue an optimized message size and incentive type that would be required to get users to cooperating. The error rate is there to give a measure of the quality of the network, whereas the delivery ration, latency, number of hops and duplication will illustrate the ability of the basic routing algorithm.

The delivery model that will be used for testing will be simulated. The simulation will consist of two pools of nodes, of which a small subset of nodes will randomly travel between the pools. Each pool will consist of several hundred nodes and all nodes in each pool will move randomly within the pool using the classic random waypoint mobility model [4]. The area of the pool used by the waypoint mobility model will be greater than the hotspot pool; only nodes within the hotspot pool will be deemed to be active. In this way nodes will appear to be moving into and out of the pools. There will be a small number of nodes that will move at random times between the two pools. This initial model will allow verification of the efficient provisioning framework with the specified benchmark protocols before moving to a more complex model.

## VI. FUTURE WORK

The next stage in this development is to test the framework using simulation beyond the benchmark protocols. The ability to set the number of nodes travelling between the two pools in the simulation will facilitate an illustration of the effect that the volume of traffic has upon transfer. Random messages will be transmitted within each pool to give the effect of normal transfers within the pool. A designated pair of nodes, one in each pool will initially be identified as source and destination. When the carrying node arrives at the other pool the message will be broadcast throughout the pool till it reaches the destination.

Once the framework has been fine tuned with the Epidemic and PRoPHET protocols, the number of designated nodes will be increased and a third pool will be added. This will allow the simulation to be expanded into a more real world type scenario. After a verified working simulation has been produced the next phase of the research can commence, with the development of new protocols that are optimized for opportunistic network scenarios. One pertinent research question to explore is an assessment of the effect of inter-pool travel has upon the whole system performance.

## Conclusions

In summary, we have identified the need to provide a robust set of assessment metrics, in order to measure the efficient of opportunistic ad-hoc networks. The absence of a pre-defined end-to-end path in an opportunistic network creates challenges for both the measurement of existing benchmark protocols, as well as the ability to assess and ultimately, design protocols optimized for these environments. We propose an initial framework that can assist the appraisal of efficient provisioning, and furthermore specify a number of pertinent characteristics that will provide a qualitative assessment of a given protocol. The framework has been applied to Epidemic and PRoPHET protocols to establish a base set of results. A simulation plan has been described to produce further results for verification.

## REFERENCES

- [1] Baldoni R., Beraldi R., Querzoni L., Cugola G., Migliavacca M., (2005) "Content-based routing in highly dynamic mobile ad hoc networks", *International Journal of Pervasive Computing and Communications*, Vol. 1 Iss: 4, pp.277 – 288
- [2] Buttyan L., Dora L., Felegyhazi M., Vajda I., (2010), *Barter Trade Improves Message Delivery in Opportunistic Networks*, Elsevier Ad Hoc Networks, vol. 8, no. 1, pp. 1-14.
- [3] Hui, P., Crowcroft, J., & Yoneki, E., (2007), 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)*.
- [4] Johnson D., (1994) *Routing in Ad Hoc Networks of Mobile Hosts*. In *Proc. of the Workshop on Mobile Computing Systems and Applications*, pages 158.163.
- [5] Lin, C., (2004), *AODV Routing Implementation for Scalable Wireless Ad-Hoc Network Simulation*, Technical Report, 040421-swans-adv, Cornell university, April 2004
- [6] Lindgren, A., Doria, A., and Scheln, O., (2003) *Probabilistic routing in intermittently connected networks*. In *Proceedings of the Fourth ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc 2003)*.
- [7] Liu J., & Sailhan, F., (2005) *Group Management for Mobile Ad Hoc Networks: Design, Implementation and Experiment*, In *Proceedings of the 6th international conference on Mobile data management*.
- [8] Niazi, M., (2008), *Self-organized Customized Content Delivery Architecture For Ambient Assisted Environments*, In *Proceedings of the third international workshop on Use of P2P, grid and agents for the development of content networks (UPGRADE '08)*
- [9] Rangarajan, H., & GarciaLunaAceves, J.J., (2004), *Using Labeled Paths for Loopfree OnDemand Routing in Ad Hoc Networks*, In *Proceedings of Mobile Ad Hoc Networking and Computing - MobiHoc*, pp. 43-54, 2004
- [10] Song, L., & Kotz, D. F., (2007), *Evaluating Opportunistic Routing Protocols with Large Realistic Contact Traces*, In *Proceedings ACM 2nd Workshop on Challenged Networks (CHANTS '07)*, pp 35–42
- [11] Vahdat, A. & Becker, D., (2000), *Epidemic routing for partially connected ad-hoc networks*. Technical Report CS-200006, Duke University.
- [12] Verma, A. & Srivastava, A., (2011), *Integrated Routing Protocol for Opportunistic Networks*, *International Journal of Advanced Computer Science and Applications*, Vol. 2, No.3.