Evaluation of a Framework for Measuring Efficency in Opportunistic Ad-hoc Networks

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Abstract—**Opportunistic networks are the manifestation of wireless ad-hoc networks where there is no continuous end-to-end path. The forwarding of messages takes place via any nodes that are encountered, and therefore the measurement of message passing efficiency between nodes becomes challenging if a number of different protocols are to be compared and evaluated. Prior work has identified an evaluation framework that addresses this challenge. This article describes the construction of a simulation tool to assist the assessment of efficiency in opportunistic networks, and by way of an exemplar case study, a set of experimental results are discussed and evaluated. From this we conclude that Spray and Focus may be the way forward in this case.**

Keywords-Ad hoc network; opportunistic network; metric; routing; simulation

I. INTRODUCTION

The organization of Ad-Hoc wireless networks is such that they do not rely on any infrastructure such as access points etc. Each node can act as both an end point in the system, and also as a router to forward messages to the next node, working together as a multi-hop wireless network. However, they still require a continuous end-to-end path in order to route messages to the required destination node. For Opportunistic Networks (ON) the need for a continuous end-to-end path is removed, permitting communication to take place in its absence. A preliminary literature review has revealed a number of measurements that appear to apply to ONs, but to date little has been reported in terms of assessing the efficiency of ONs. As a result of this a framework to assess qualitative and quantitative metrics was proposed to evaluate the performance of ONs [9].

The objective of this article is to describe how this assessment framework can be applied, and through simulation indicate the way that the effectiveness of the framework can be assessed. There are a number of simulators available that have the capability to simulate opportunistic networks. The simulator used in this research is the Opportunistic Network Environment (the ONE) simulator [6].

The rest of the article is structured as follows: Section 2 briefly introduces the key characteristics of the proposed framework. Section 3 introduces the case study used as the basis of the simulation runs, whilst Section 4 describes the design of the simulation study and the experiment. The results are discussed in Section 5, after which conclusions and future research directions are articulated in Section 6.

II. PRIOR WORK

The framework of metrics to evaluate the performance of opportunistic networks that was proposed in the paper by [9] is shown below in Table 1.

These metrics were chosen to represent a common set of characteristics that were collected from the current literature base. It was evident that a wide number of characteristics were presented, which creates difficulties when comparing the relative performance of differing protocols. A standardized set of measurements would therefore facilitate robust investigation into both existing and emerging protocol designs, and thus a uniform framework was required. The generation of messages and their subsequent propagation, has an adverse impact upon the resources consumed by the device. For this process to take place there is an associated power cost, as well as the use of device storage and network bandwidth. How the node behaves will have a direct bearing upon the metrics, since a node may choose to conserve power by reducing transmission activity or perhaps delete messages in order to conserve storage space. Whilst an individual node may only be interested in its own priorities, there is also the holistic 'altruistic' perspective that will be considered here.

The Peak Messages metric indicates the peak demand placed upon a network, and although this tends to be transient in nature it will be of particular interest for measurement since the designer of the network needs to consider the peak load carrying capability of the network. Protocols that produce significant duplication of the messages in order to achieve their objectives will significantly add to the network load, flooding protocols such as Epidemic [12] being a case in point.

The ONE simulator was designed specifically for Opportunistic or Delay Tolerant Networks. In the ONE simulator, rather than the simulation being based around the emulation of routing protocols, it is primarily focused on the movement of nodes around a three dimensional environment, whereas routing is considered a secondary priority [6]. This can be thought of as more like a turn based game. All nodes move, adjacencies are calculated, and if within proximity of each other, a connection may be established.

TABLE I. FRAMEWORK CHARACTERISTICS FOR THE MEASUREMENT OF OPPORTUNISTIC NETWORK EFFICIENCY.

Metric	Description
Network Load	Maximum number of messages that busiest node in the network passes
Delivery Ratio	Ratio of messages delivered to messages generated
Latency	Delay measured for packets travelling end-to-end across the network
Number of Hops	Number of hops taken by a packet from the originator to the destination
Power Usage	The power usage required to transport the message
Peak Messages	Maximum number of messages that busiest node in the network passes
Message Duplication	Number of times a message was copied
Error Rate	Ratio of packets with errors received to the total number of packets received

It is possible for the environment to exhibit more complexity with different types of nodes, for instance pedestrians, cars, busses, trams and trains as one example. This allows a realistic environment to be created without the need of external data capture.

Within the simulator there are a number of mobility models available. A composite movement model consisting of two modes was selected for this study. Random Waypoint [5][1] and Shortest Path Map Based Movement [2] were the two selected. The Random Waypoint model attempts to capture the movement of humans, and each node is given random coordinates in the simulation area (waypoint), the node moves at a constant velocity directly to the given waypoint. At this point the node pauses and a new waypoint is defined together with a random velocity.

The waypoints are uniformly distributed over the simulation area and nodes move in a characteristic zigzag pattern. The Shortest Path Map Based Movement model is one of a number of Map-based movement models. In Map-based models, movement of the node is constrained to a path as defined in a set of map data. In the Map-based model, nodes are able to move randomly along any path, whereas in the case of the Shortest Path Map Based model, nodes follow the shortest route to a point on the map. This point on the map is chosen either as a random point on the map or from a list of Points of Interest. In this case there will only be a single Point of Interest provided.

There have been a significant number of protocols created to support ONs. In this study we will be restricting the evaluation to two of the main benchmark protocols, which are Epidemic routing [12] and Probabilistic Routing Protocol using History of Encounters and Transitivity, PRoPHET [7].

The Epidemic protocol [12] is said to be context oblivious, in that it takes no notice of the current state of the network or current node when forwarding messages to nodes. The Epidemic protocol 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 are 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 receive forwarded messages. Not only does this cause congestion, but it is also a wasteful consumer of other resources, such as bandwidth, storage, and power.

The PRoPHET protocol [7] 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

III. CASE STUDY

We shall now explicate the use of the framework by considering a simple case study. A town center or shopping mall Contains a base network infrastructure of Wi-Fi routers configured to work in Ad-hoc mode, which are distributed throughout the shopping mall.

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.

The simulation scenario is described as follows:

```
ndes          ← target_number_of_nodes
max_sampled ← max_nodes_to_sample
nsent         ← 0
nchecked      ← 0

while(nsent < ndes) AND (nchecked<max_sampled)
    nchecked ← nchecked + 1
    if ISEMPTY({destn_history_node(nchecked)}∩
                                         {preferred_destns})=FALSE
        if ISEMPTY({direction_node(nchecked)}∩
                                          {desired_directions})=FALSE
             if CARD{packages_node(nchecked)}<
                                            capacity_node(nchecked)
                 packages_node(nchecked) ←
                         packages_node(nchecked)+{message}
                 nsent ← nsent + 1
              endif
         endif
    endif
end
```

The aim is to select a number of nodes to carry the message that have previously been in contact with the destination are moving in the right direction and have the capacity to carry the message.

Has the node been there before?

```
if ISEMPTY({destn_history_node(nchecked)}∩
                                         {preferred_destns})=FALSE
```

Might the node be going in the right direction

```
if ISEMPTY({direction_node(nchecked)}∩
                                      {desired_directions})=FALSE
```

Has the node capacity for the information

```
if CARD{packages_node(nchecked)}<capacity_node(nchecked)
```

If yes then attach the message and continue till all the required nodes are carrying messages.

IV. Simulation Study

There was an initial learning curve in using the ONE simulator, which mainly revolved around understanding what the terms they had used did. They do include a good number of example configuration files with the downloaded source code of the simulator to assist with this. It is Java based and needs to be compiled before use; a suitable batch file is included. The configuring of the simulator is via a text file; by trying the different examples, parts to make up a simulation based on the case study were identified. Running the new configuration file identified missing parts, especially the lack of some of the required metrics. The program itself is very large but it is broken up into small single function packages. All results that are generated by packages are situated in the report subdirectory. By simple modifications to the code in a two of these packages the required metrics were produced.

In order to match the case study as near as possible a composite movement model consisting of three modes was used.

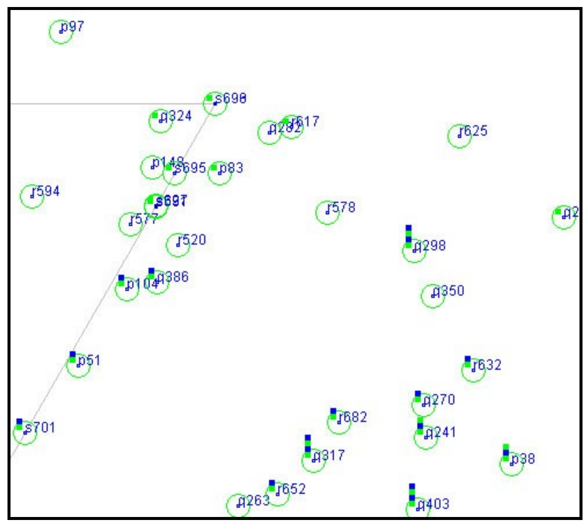
1) *Group 1 was set to be static, and consisted of 4 nodes evenly distributed in the main area.*

2) *Group 2 was set to pedestrians using the Random Waypoint model in the main area, and consisted of 230 nodes.*

3) *Group 3 was set to be pedestrians using the Shortest Path Map Based Movement, and consisted of 25 nodes randomly distributed on the defined map.*

The main area consisted of an area of 3500 by 2400 units, passing through this area was part of a circular 'map' which contained a single point of interest situated outside of the main area. The path through the map was defined as one-way. The group 1 nodes generated messages for the point of interest at random intervals between 25 and 35 seconds. The communication range was defined as 100 units for all nodes. All other settings were left at the default levels. Modifications had to be made to the Java code for the reports in order to obtain the metrics that have been specified. The graphical output of a run of the simulator is shown in Figure 1, shown is part of the main area with the path running through. Nodes starting with an s are those following the defined path all other nodes are moving randomly. The small squares next to the nodes are the messages that each node is carrying.

FIGURE I. SIMULATION SHOWING NODES AND PATH



V. Evaluation

The average results of a number of runs with each protocol are shown in Table 2.

TABLE II. SIMULATION RESULTS.

Metric	Epidemic	PRoPHET
Messages Injected	1461	1461
Delivery Ratio	0.24	0.28
Latency	4163	3969
Number of Hops	4	3
Power Usage	N/A	N/A
Peak Messages	81496	69425
Message Duplication	56	47
Error Rate	0	0

From Table 2 it can be seen that there is a difference between the two protocols with PRoPHET having lower values across all the metrics, which supports the published theory with regard to the improvement of PRoPHET over the Epidemic protocol. The intention of the framework 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 will inform the strategy for implementing compound protocols.

In this work we are looking for efficiency of the ON and have derived a range of metrics that are of relevance. It is the combination of these metrics that will give a representation of network efficiency. In the case of the two protocols that were assessed here it is clear that the PRoPHET protocol is the more efficient one since it uses fewer resources to achieve communication. Whereas in another situation, in ensuring that every node in the main area received the message, Epidemic would be more efficient. In the case of a sensor network it may be more important to conserve power usage and sacrifice the delivery ratio. This would indicate that the framework was still valid just that the interpretation of what efficient means in each case needs to be assessed.

Examination of the original framework shows that Network Load and Peak Messages have the same definitions. It was decided to drop Network Load in favor of Peak Messages as it has a more descriptive title as to what it represents. What was added to the framework was Messages Injected which gives a record as to the total messages inserted from the source nodes.

The limitations with the current simulation are:

1. Further work is required with regard to Power Usage in order to achieve a meaningful value, which is why it is not included in table. The power consumption of our new power hungry devices is of significant concern to users. If carrying and transferring messages significantly increases the power consumption users will not engage with the process. So a scheme to understand and categorize the power requirements is important in order to optimize the process. It is assumed that there are three categories, the power required to maintain an active wireless connection, the power to send a message and the power to receive a message. It will be the management of these categories that will allow the optimization.
2. Currently the simulation is only providing the messages require going to the point of interest, in a real world situation there would be significant other traffic in the main area which would result in an increase in the error rate. The current simulation is only addressing the special case of requiring a message to be delivered to a remote site. The normal case will be of multiple messages in the main area. So the special case will need to be able to deal with this high rate of local traffic. This would be the next to be implemented using the Epidemic protocol for communications. Another source of errors in the real world would result from interference. Using Wi Fi in the 2.4GHz band will have to contend with a whole host of other devices, such as microwave ovens, Bluetooth, remote controls and wireless phones. This will tend to create areas of poor or no signal strength which will impact on message quality. This is currently not built into the simulator at this time.
3. The current simulation provides two significant aspects of the full case study. The final part of the case study will be met by replacing the point of interest with another shopping mall. Adding another area of random nodes will simulate the other shopping mall. This will allow us to investigate the transition of messages from a mobility protocol into a flooding type of environment. Also by including further context information, such as details of where it came from and by whom it was carried, it opens up the opportunity for investigation into the management of that information for usage such as financial incentive schemes.
4. Only two protocols were used in the simulation, a more appropriate protocol may be readily available. Such as Spray and Focus [11], although not currently available in the simulator a version of the protocol has been programmed. A starting point would be to assess the Spray and Wait [10] protocol which would give an indication of possible improvements that could be achieved without any context information.

VI. CONCLUSIONS

In summary, we have measured a framework of assessment metrics as generated by a simulation of a given case study, in order to measure the efficient of opportunistic ad-hoc networks. The framework has been applied to Epidemic and PRoPHET protocols to establish a set of results. 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. Both protocols as simulated ran as expected, assessments have been made on the validity of these protocols [6] as compared with similar implementations on other simulators. Although the ONE simulator is constantly been improved with new protocols and mobility models the areas used in this work have been stable for some time.

The use of the case study provides a fairly challenging environment for the protocols, once injected the messages move through the local nodes that are using the random waypoint model. Due to the size of the area and the transmitting range of the nodes this can take several minutes before the nodes in the vicinity of the path become infected and ultimately a node using the mobility model receives the message, to transport to the point of interest. Using this basic simulation and measuring up till the messages reach the point of interest provides a usable measurement and the ability to compare different protocols. However, in order to full implement the case study the simulator will need further modifications to allow for two random areas connected via a map. An alternative solution would be to map two local shopping malls and then connect them together. This would then allow future development of actual mobility patterns into the simulator.

In the current simulation there were no interfering messages to affect the main message. In order to produce a more realistic real world simulation we need to look at the effects of increasing the levels of local traffic. This will allow examining error levels and the effects on power usage. At high levels of local traffic nodes could decide not to carry our long distant messages. The other source of errors is interference; however, this is not built into the simulator at this time. It is an area that should be investigated at some point in the longer term.

During the initial simulation the Power Usage Report did not function how it was expected to work. Since this is seen as an important metric for the framework further work is needed to get this report functioning correctly. Although the current implementation in the simulator produces a single value a more useful output may be a list showing the level for each category of how it was produced in order to optimize the overall power usage.

Once the full set of metrics are fully functional measurements of other protocols against the same case study will be carried out to further verify the framework. The next protocol will be Spray and Wait [10] to set a base level for testing Spray and Focus [11]. Simulations using alternative mobility models and varying the levels of local traffic will provide a more complete picture of what is possible.

We anticipate that further work will enable patterns in mobility to be identified, which is of particular interest to our research. The simulator will be required to model mobility patterns, which will augment the existing model with additional characteristics. Mobility models such as the Working Day Movement model [3] and the adaptation of a Markov chain [8] will be investigated. Although work on measuring actual human mobility in shopping malls [4] is showing patterns not previously identified in the other models so will need also to be investigated. Including the observed pattern where users tend to remain stationary for long periods in given places.

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