Developing and Evaluating Routing Protocols for Rural Areas That Communicates Via Data Mules

Xoluqobo Mkhwanazi
Computer Science Department
University of Cape Town
Cape Town, South Africa
e-mail: xmkhwanazi@cs.uct.ac.za

Hanh Le
Computer Science Department
University of Cape Town
Cape Town, South Africa
e-mail: hanh@cs.uct.ac.za

Edwin Blake
Computer Science Department
University of Cape Town
Cape Town, South Africa
e-mail: edwin@cs.uct.ac.za

***Abstract* — We investigate and enhance the protocols that can bring connectivity to isolated village networks via multiple data mules. These multiple mules communicate in order to find shorter reliable routes and provide higher probability of message delivery. Using movement traces for multiple data mules for rural-like areas the existing protocols *ad hoc on-demand distance vector protocol* (AODV) and *optimal relay path* (ORP) were compared. The results show that a rural route can provide telecommunication between the village networks, furthermore that AODV was more applicable to the network than ORP especially as the number of mules increase. Two enhancement algorithms (data mule inter-communicator (DMI) and ultimate data mule inter-communicator (UDMIC)) were developed using the existing protocols. The first enhancement was DMI that is based on *using clustering of data* to improve the performance between rural networks. The second enhancement was UDMIC, *an adaptive algorithm that examines the situation* to select an algorithm to improve performance. This enhancement not only managed to use the best of each protocol but in some cases improved network performance.**

Keywords-isolated network; vehicular network; data mules; rural areas

I. Introduction

As abundant as technology appears to be, not all places in the world have the adequate infrastructure to support technologies. Computer networks allow for communication between people, but rural areas do not have the adequate infrastructure to enable innovative communication via computers. To provide a possible solution for this, a creative method of providing telecommunication is explored. Taking the example of rural areas in the Transkei, South Africa; there are villages that cater for both residential and business purposes with people travelling between villages. By using existing resources communication networks within the villages can be created, but because of the distance between the villages there is no direct communication available. A data mule, which is a combination of mobile entity and an electronic device that uses the local commuter system to provide communication between the village networks, can provide an alternative [1].

We first considered the feasibility of using a public route to provide telecommunications to isolated village networks. A working project DAKNet provided a similar solution, whereby using local public transport (i.e. minibus taxis and buses), as data mules, the isolated networks points were connected [2,3]. This is shown in Figure 1.

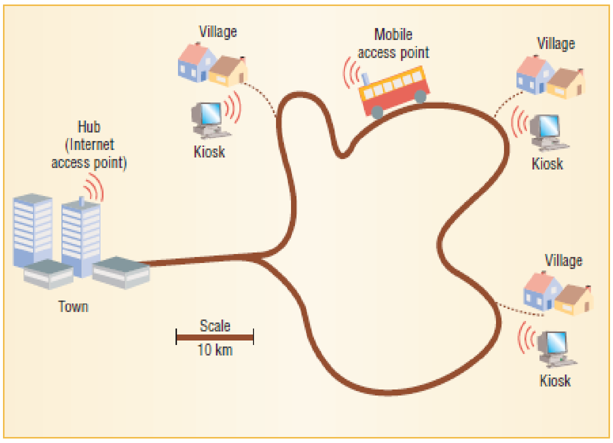


Figure 1. DAKNet's usage of data mules.

To explore the question further a simulator that uses a rural area map similar to one in South Africa was created and mobility traces from a realistic vehicle movement simulator (VanetMobiSim) were used. Using the simulator, a pilot study [4] was conducted that showed the appropriateness of the map and further showed that it was possible to deploy a network using the commuter route. The Mule Inter-Communication (DMI) algorithm was detailed in that paper. In this paper we address three further questions that guided the research. The first question is "*How would existing routing protocols perform in rural networks scenario using multiple data mules?*", this is followed by looking at "*Does the use of clustering of data mules improve the performance e.g. latency between rural networks?*" and finally finishing off with "*Can an adaptive algorithm be developed that makes use of existing protocols to improve performance rural networks?*".

II. Simulator Creation

The VanetMobiSim [5,6,7] software allows for the collection of realistic mobility traces instead of going into the field and riding taxis. The VanetMobiSim uses xml files and a variety of constraints that allow the user to collect mobility traces. For this project, a map was chosen from a relatively remote area. The map is distributed freely by TIGER/Line USA. Since the simulator used files in TIGER format and South Africa map files were not available and since we were only interested in the general characteristics of the map, the closest possible match was found in a rural area in the USA. For testing six village areas were chosen and isolated networks placed. There were five areas surrounding the network and one in the centre as shown in Figure 2.

Figure 2. Simulation map with the village network.

The parameters that could be applicable to a rural network are the ranges of the isolated networks, the mule range and message times as well as the simulation time. The simulation was run for 10000s (approximately 2hrs 45minutes). This may appear to be short for a delay tolerant network (DTN), as it experiences heavy latencies. However taking into consideration that the taxi/bus follows the same schedules continuously over the day and that the simulations ran six times with different message sets, the experiments essentially covered over 12hrs.

III. ROUTING PROTOCOLS

Since the aim is to evaluate routing protocols that can be used in isolated networks that are connected via data mules, various possible routing protocols to be discussed.

With regard to evaluating the performance of flat routing protocols, high node mobility rates, high node speed and changing network topology were explored. Based on the different performance evaluations, AODV and OSLR performed well in a variety of circumstances [8, 9, 6, 10]. ORP is a unique algorithm that was considered and its primary design was to function within disconnected MANETs. Finally a new algorithm called Ultimate Data Mule Inter-Communicator was introduced and evaluated.

A. Why AODV

The routing protocols AODV, DSR, OSLR and DSDV, are some of the protocols that have had performance evaluations [11, 9, 12]. These performance evaluations are important in understanding how a routing protocol designed for MANET may be applicable in a VANET, and how they might perform.

The movement speed of the nodes is a key factor that determines how well a routing protocol will perform. In [11, 12] Brochette *et al.* and Said *et al.* performed a performance evaluation of the DSDV and AODV protocols for varying mobility and movement speed in a MANET. Mobility rate refers to how often a node moves. It was found that the AODV protocol performs well at all mobility rates [11, 12] and movement speeds, whereas DSDV performs well at low mobility rates and movement speeds [11].

Another key factor is network topology and, in a VANET, the network topology changes constantly. In [13] Mbarushimana and Shahrabi conducted a performance evaluation to compare OLSR, DSR and AODV in MANETs with different network conditions (network size, stresses and topology changes). The results showed that reactive protocols (DSR, AODV) did not perform better than the proactive protocol, OSLR. DSR and AODV experienced high data loss and delay especially with a high load, whereas OSLR routes are readily available. This was mainly due to the fact that OSLR had constant knowledge of the network topology [13].

B. Optimal Relay Algorithm

In [14] Rus and Li introduced the optimal relay path (ORP) algorithm. This algorithm is a hybrid routing algorithm that uses a flat routing scheme, as well as the geographical location of the node.

The main aim of the ORP algorithm is to find the shortest time strategy to send a message from one host to another. Mobile hosts are simply mobile computers. The ORP algorithm works on the assumption that in an ad hoc network of mobile computers the trajectory of each host is approximately known.

ORP uses optimal trajectory for relaying messages. The optimal trajectory uses mathematical geometry to calculate the path and time a host should use in approaching another host, assuming the known maximum speed of the host. This enables ORP to determine a minimum time path from one host to another.

The basic structure of the algorithm described above may be applied to a MANET to facilitate communication between isolated networks using data mules. The ORP algorithm decreases time delays in message transmissions between hosts. It is also effective in that it allows communication between hosts that are isolated from each other. The ORP algorithm, however, cannot deal with a large number of hosts because every host must know where every other host is. As more hosts are added to the system, it takes longer for these hosts to locate each other. This increases the margin in error when relaying messages.

C. Ultimate Data Mule Inter-Communicator

The UDMIC (Ultimate Data Mule Inter-Communicator) algorithm is intended to improve efficiency, adaptability and feasibility when connecting isolated networks via multiple data mules. It uses principles from four protocols: ORP, Simple Clustering Algorithms [15, 16, 17], OLSR and ZRP [18]. A framework called OZRP was designed that used link priority lists for each node to determine which protocol to use in sending messages to different nodes.

The OZRP framework is based on the OLSR and ZRP framework. The OLSR framework is a proactive routing protocol and this means that if there is a route available it is always available. Furthermore, each node periodically maintains 1-hop and 2-hop neighbourhoods and this allows the protocol to have on-going knowledge of the network. Using this network knowledge, the ZRP framework may be more applicable to disconnected networks. The ZRP divides the network into zones and uses two different protocols to transmit data.

The OZRP framework uses these principles and aims to create a framework that allows the use of different protocols for different environments that will yield good results in terms of message delivery and route location. The framework uses a set of links in order to maintain a neighbourhood for a node. The links accumulate points that aid the nodes in making use of their strongest relationships. Figure 3 displays the layout of the priority link list of node A, where most connected nodes are those with more than X points.

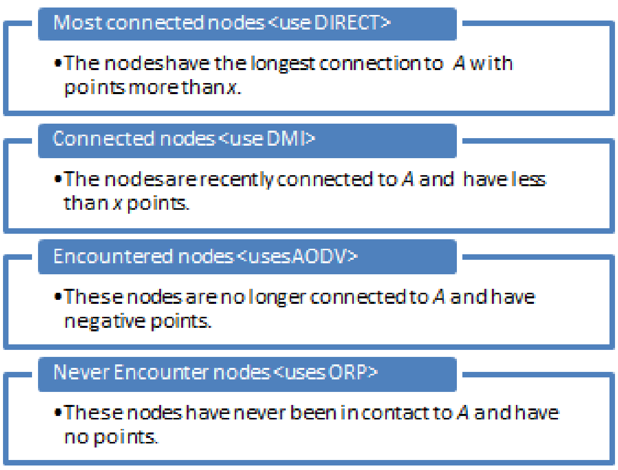


Figure 3. The three components used in the UDMIC.

Each node in the network has a link priority list. The list maintains at most 2-hop neighbourhood links. The list is a priority queue; the longer a node is within range of another node, the more rapidly it will move up the list. There are a limited number of points that separate the most connected and recently connected nodes. This chosen value is *x*. The nodes that are no longer connected accumulate negative points; this gives the list holder node an idea of the length of the nodes' disconnection.

Using the priority list, a node can decide which protocol it should use when sending data. For instance, if the node is already connected to the receiver node it can send the data directly or use the DMI algorithm. If the receiver node used to be connected, it may use the AODV protocol and if the receiver node has never been connected, it may use the ORP algorithm.

The adaptive UDMIC protocol operates as follows: The DMI algorithm is suited for nodes that are already connected as it uses clustering algorithms to find routes along which data can travel. The AODV algorithm suites previously connected nodes, as it finds routes only when they are required. Finally, since the ORP algorithm uses expected movements to determine routes, it works well to find routes to nodes that have never been connected.

IV. Results

The simulation was run for all the algorithms developed and for each algorithm there are six sets of message sets that contain 100 messages each. For each message, certain message and routing data was collected. The collected data was used to develop ratios that will be used to aid in answering the research questions. The messaging ratios developed are the message delay, delivery and success rate. This aids in focusing in the efficiency of the algorithm, whereas the other ratios aids in focusing on the intelligence of the protocol/algorithm. No routing ratios were developed instead the routing parameters: route discovery time, the number of requests, time to send a message on a route, one hop usage and end-to-end message time is to be grouped.

We first present the initial results that were collected from a preliminary study to show feasibility of the map and mule to mule communication. Next we evaluate existing routing protocols that were implemented (AODV and ORP) for the DTN parameters. This is followed by an evaluation of the effect of clustering in DTN. Finally (D) we evaluate the hybrid algorithm (UDMIC) that attempts to use the best algorithm when sending a message.

A. Preliminary Study

Communication between the data mules was investigated and we tested the simulator and map. Two algorithms were tested: optimal relay protocols (ORP) and data mule intercommunication (DMI). The design of the DMI is presented as well as the results that would later affect the decision regarding the final algorithm that was developed.

This study demonstrated the use of clustering and data mules on the map. It tested the possibility of communication between clustered data mules (without the isolated networks) and in so doing tested the simulator that was built. The new algorithm, DMI, that integrates ORP and a simple clustering algorithm, was then tested against ORP.

From the study it was found that the DMI improved the ORP algorithm marginally as shown in Figure 4. We found that in the cases of 10m and 100m mule communication range there was a small increase in DMI algorithm performance versus the ORP algorithm. Overall as the number mules and the communication range increased so did the percentage of successful messages. This was also an indicator that the algorithms could be applied to a DTN and that limiting cluster sizes was recommended. Furthermore, the study showed the applicability of clustering in a sparse network.

B. AODV vs. ORP

We implemented and valuated existing routing protocols not designed for DTN, namely, AODV and ORP. ORP and AODV may both be applied to a DTN, however because

ORP makes no use of hops the protocol made no real contribution in DTN.

Initially ORP has a similar delivery rate than AODV (see Figure 5). However as the number of mules increase, AODV's delivery rate increases. This is evident especially at 35 mules where the ORP struggles to maintain the increased number of mules, the AODV performs well. Although in the rural area, the number of mules would be low, at approximately between 5 and 15 mules. Even so AODV has a slightly higher delivery rate in comparison to ORP.

In Figure 5 the percentage of usage of a hop for routes used by protocols is presented. ORP does not use any hops between data mules. ORP is unable to use other mules because its prediction algorithm is not able to see any benefit in doing so. Most of the routes found by AODV include one hop between the mules, and this aids the good performance. This was seen with a higher delivery rate, the end-to-end message time as shown in Figure 5 and lower message delay. AODV makes use of one hop for most of the routes used and this directly correlates with the better delivery rate.

This also validated the use of a hop between data mules for better communication. It was concluded that AODV was a better fit, as it was more directly applicable to the presented DTN. One of the reasons ORP did not have the ability of perform well was the lack of hop use, and as a means to introduce a hop between data mules clustering is introduced to the protocol.

C. *Effects of Clustering*

Our DMI protocol makes use of clustering in its communication was compared to ORP. DMI is designed to address ORP's decreased performance when there are many nodes in the network by using clustering.

Starting with delivery rate and message delay it was already noted that clustering did not change the performance of ORP. Not only were the results closely similar, the packet traffic in the network increased because of the cost of maintaining and creating clusters. Upon further investigation to understand why, it was discovered the new algorithm (DMI) that uses both clustering and ORP, was using ORP more than 70% of time to send messages.

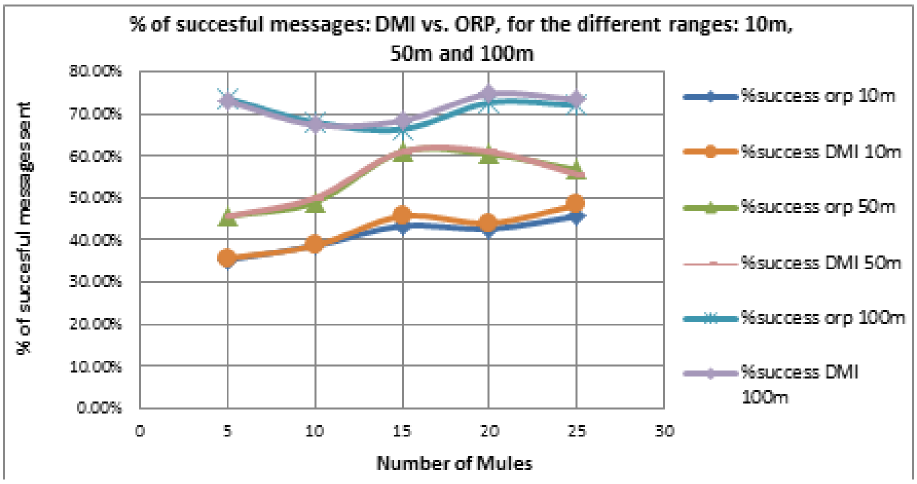
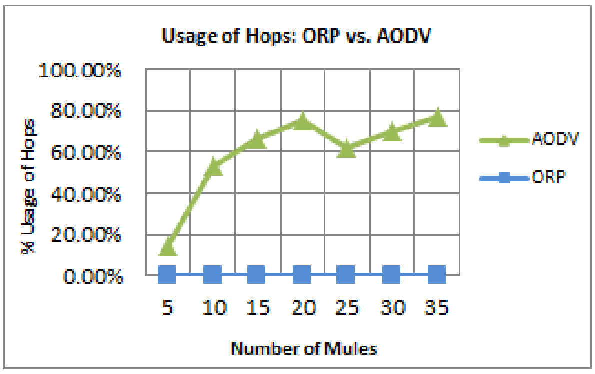


Figure 4. Number of Successful Messages – ORP vs. DMI.



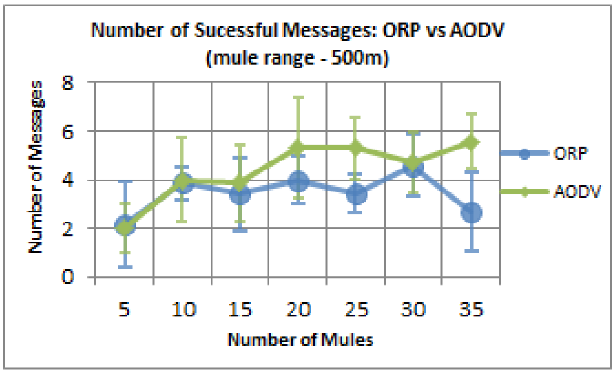


Figure 5. Usage of Hops: ORP vs. AODV and Number of Successful Messages Delivered for 500m mule range – ORP vs. AODV

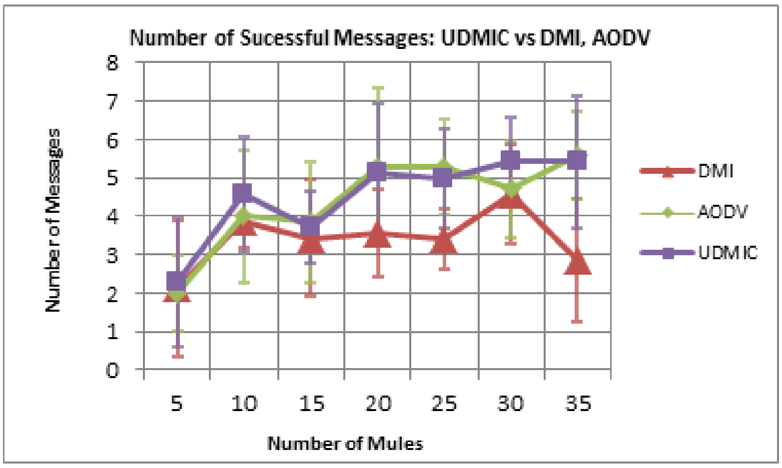


Figure 6. Number of Successful Messages: UDMIC vs. DMI, AODV

Furthermore almost no routes with a hop between data mules were generated. However, stable clustering in a DTN was possible. We concluded that clustering did not necessarily promote usage of hops between data mules. While creating and maintaining clusters was possible, the members of clusters were continually changing. It is not recommended to use clustering for the DTN we investigated.

D. UDMIC

The UDMIC is algorithm designed to utilize the best properties of each protocol that was implemented. It incorporated DMI, ORP and AODV. ORP made no use of hops, but it performed well for a lower number of mules and badly for higher number of mules. AODV performed extremely well for high numbers of mules but its performance was very close and slightly worse than ORP for lower numbers of mules. Taking this into consideration the UDMIC was implemented and evaluated. This algorithm was evaluated on its ability to follow the trend of producing the best results for the DTN, and it did so. It some instances surpassing the trend, showing the combination of the protocols were valid. This is clearly shown in Figure 6. UDMIC performs better than DMI and AODV for fewer than 15 mules, after which it tracks AODV closely. Our algorithm that uses existing protocols can outperform its components.

V. DISCUSSION

It was demonstrated that between the two existing routing protocols implemented that AODV performed well in a DTN. AODV provides better performance (message delivery, lower overhead and better routes). AODV also promoted mule to mule communication, and as the number of mules increased, the higher the percentage of hops between the mules became. ORP made no use of hopping between data mules, which made it not applicable. However the ORP result still showed the feasibility of using a data mule to send messages between isolated networks, whereas AODV showed the applicability of multiple data mules as means of improvement.

As a means to stimulate the use of at least one hop between data mules with ORP, clustering was introduced. It did not improve the performance because of the high mobility and low number of data mules. It was found that although clustering and maintaining clusters was possible in DTN, the changing cluster members provided the added issue trying to find a route between clusters difficult. Furthermore it showed that the algorithm – DMI (designed to use clustering and ORP) would choose ORP over clustering methods.

UDMIC was designed to take the best of AODV and ORP, to try to further maximize the performance of a protocol in DTN. ORP showed that in some cases there was no need to have a data mule communication as it makes little difference. UDMIC however showed that the combination of the protocols increased network performance. UDMIC performed better than DMI and AODV and showing the ability of choosing which is applicable for a different situation.

VI. CONCLUSION

The guiding questions from the introduction have been answered. The question "*How would existing routing protocols perform in rural networks scenario using multiple data mules?*" was answered by the implementation and evaluation of the ORP and AODV. ORP and AODV are both applicable for a DTN, however because ORP makes no use of hops the protocol made no real contribution to be used in DTN.

The next question was "*Does the use of clustering of data mules improve the performance e.g. latency between rural networks?*" In answering this question, starting with delivery rate and message delay, it was already noted that clustering did not change the performance of ORP. Not only were the results closely similar, the packet traffic in the network increased because of the cost of maintaining and creating clusters. It was concluded that clustering did not necessarily promote hops between data mules, however creating and maintaining clusters was possible, but the members of clusters are always changing.

The final question that was “*Can an adaptive algorithm be developed that makes use of existing protocols to improve performance rural networks?”* The algorithm (UDMIC) built using DMI, ORP and AODV. ORP made no use of hops, but it performed well for a lower number of mules and badly for higher number of mules. AODV performed extremely well for high numbers of mules but was very close and slightly less than ORP for lower numbers of mules. Taking the two into consideration the UDMIC was implemented and evaluated. This algorithm was evaluated on its ability to follow the trend of producing the best results for the DTN, and it did so. It some instances surpassing the trend, showing the combination of the protocols were valid. This also showed that an algorithm that used existing protocols could be developed and can perform even better.

These results provide intermediary steps for providing communication to DTN in our proposed rural area. Furthermore, the study shows the applicability of existing protocols to DTNs.

VII. Future Work

This paper provides a platform for a variety of future work. The most obvious is using rural are map from South Africa. In order to do so field work would performed to collect the necessary data. This will allow for the testing of the algorithm (UDMIC) and protocol (AODV) that performed well in the evaluation in the field. The results would provide as baseline platform to how AODV and UDMIC would perform in the real world. For further testing DTN can be explored as a scientific discovery.

Since the data mules where already semi-vehicular, another form of future work can include the testing the algorithm developed UDMIC with VANets and understanding how this would behave.

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