

Towards Designing a Routing Protocol for Opportunistic Networks

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Abstract — Intermittently connected opportunistic networks experience frequent disconnections and shorter contact durations. Therefore routing of messages towards their destinations needs to be handled from various points of view. Predictability and connectedness are two features which can be determined by participating mobile nodes of an opportunistic content distribution network using their past contacts. Epidemic or probabilistic routing protocols such as PROPHET do not fully utilize these features to route messages towards their destinations. In this paper we describe the design, implementation, experiment set up and the performance validation of a new, adaptive routing protocol which utilizes the predictability and connectedness features to route messages efficiently. Simulation based comparative studies show that the proposed routing protocol outperforms existing Epidemic and Probabilistic routing protocols in delivering messages.

Index Terms — Opportunistic networks, Adaptive routing protocol, PROPHET routing protocol, Epidemic routing protocol

I. INTRODUCTION

Intermittently connected opportunistic networks operate in scenarios where wireless mobile devices establish pair wise contacts and exchange content of interest [3, 11, 12]. Routing and forwarding of messages towards their destinations in this type of networking is a challenging task due to the uncertainty of node mobility and frequent disconnections between node pairs [4, 16]. There exist few routing protocols that try to maximize the utilization of contact opportunities and forward messages towards their destination nodes. These approaches vary from flooding the network with redundant messages [17] to forwarding and routing copies of messages through probabilistically determined paths [13]. All of these approaches have their own pros and cons and there is a real need to route packets towards destinations in an optimized way that utilizes the minimum resources available in the nodes and maximizes the chances of successful delivery of messages. Our studies

[10] indicate that there exists a need to address the shortcomings of existing protocols and to propose newer protocols that can better fit in this type of networking environments.

In this paper, we describe our proposal for a new adaptive probabilistic routing protocol that utilizes each node's Predictability and Connectedness [10] information to route messages towards their destinations. Nodes determine their predictability and connectedness with their neighbors by applying probabilistic estimations on their past contact history with such nodes. Nodes then propagate their predictability and connectedness of contacts information with their neighbors and this information is utilized by the neighboring nodes to choose the best forwarder node for their messages when they generate traffic or when they store, carry and forward messages for their neighbors.

Since our approach uses the predictability and connectedness of node contacts and uses this information to determine the best contact opportunities and the best message forwarders in order to forward messages towards their destinations, our approach is different from other approaches, especially from the probabilistic approach mentioned in [13]. Our approach makes the best use of information available in the nodes and therefore maximizes the chances of message delivery.

Contact predictability, connectedness and contact quality information are maintained in each node in the form of contact history. Based on the contact history, nodes make contact predictions about future meetings with their peer nodes with given levels of certainty. These simple predictions drive the opportunistic forwarding mechanism: they are used by nodes in selecting the best node to forward messages for others. Nodes only forward messages when they opportunistically meet the best forwarder node for that message.

For the validation of our adaptive probabilistic routing protocol we use connectivity models [9] to regenerate pair wise node connectivity with given levels of confidence of predictability and connectedness of contacts within the given time intervals using the extracted probabilistic properties of real field trace set [12]. We then use simulation based experimental studies to model node connectivity and traffic generation and then collect experimental results. Our experimental evaluations show that our adaptive routing

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protocol outperforms the other two protocols with various performance indicators.

II. BACKGROUND

Proposing and designing routing protocols has received enormous attention from the Mobile Ad Hoc Networks (MANET) research community. Traditional MANET routing protocols try to find an end to end path to route packets from source node to destination node and use proactive and reactive routing techniques to establish paths before forwarding packets towards their destinations. The application of routing protocols such as Ad-hoc On demand Distance Vector routing protocol [15] and Dynamic Source Routing protocol [8] which assume the availability of an end to end path between the source node and the destination node do not perform well in the presence of intermittent connectivity.

The Epidemic routing protocol is one of the earliest protocols for routing in DTNs [17]. The basic idea is very simple: source nodes of messages and intermediate nodes flood messages to all their neighbors to mitigate the effects of a single path failure, so that, eventually the message may arrive at the destination node. Messages are quickly distributed through the neighborhood, but significant resources from network and nodes may be wasted in this process. This approach can achieve high delivery ratios, and does not need a previous knowledge of the network [17].

The PROPHET protocol [13] estimates the delivery probability based on the history of encounters. A metric called Delivery predictability $P(a,b) \in [0,1]$, is calculated for every node a for each known destination b . Suppose that a node has a message m , for the destination d . When a contact occurs between a pair of nodes a and b , node a forwards the message m to node b only if b has a greater delivery predictability to the destination d , that is $P(a,d) \leq P(b,d)$. During the contact, in addition to the exchange of messages the delivery predictability for each node can be updated. The delivery predictability calculation is divided in to three parts. When two nodes meet each other, they immediately update the delivery predictability as shown below:

$$P_{(a,b)} = P_{(a,b)old} + (1 - P_{(a,b)old}) * P_{init} \quad (1)$$

where P_{init} is an initialization constant. If, for a period of time, a pair of nodes does not encounter each other, then the delivery predictability metric is updated by the nodes as shown below:

$$P_{(a,b)} = P_{(a,b)old} * \gamma^k \quad (2)$$

where γ is an aging constant and k is the number of the time slots elapsed since the metric was updated for the last time [13].

In pure probabilistic forwarding approaches, when a node has a packet to forward, it chooses a forwarder node independently based on some probabilistic measure and

forwards the packet towards that node. This approach does not consider other factors that could influence the forwarding decision and the nodes too do not cooperate with each other in order for the nodes to choose the best forwarder node for any given packet towards its destination. This makes intermittently connected environment more prone to losses during routing and forwarding and increases the chances of network being uncertain of the forwarding possibilities of packets.

With epidemic routing it is not possible to guarantee reliable delivery of all messages due to collisions of packets etc., even if most nodes try to forward packets as much as possible. In addition, epidemic routing protocol unnecessarily floods the network with redundant packets. Recently few attempts, which try to reduce the problems caused by flooding by means of different forms of controlled flooding etc., to control the number of times a message can be forwarded have been proposed by researchers [7].

Message ferries are introduced in a routing plan by [19], where the message ferries travel on a trajectory to provide communication services. In this routing plan two different approaches are employed to bring the nodes and the ferries closer to each other. On one hand the message ferries can choose a trajectory to contact nodes and on the other, nodes themselves can move near to a pre-defined trajectory at a certain time to exchange packets with message ferries.

Recent work in opportunistic routing environments use erasure coding based techniques to balance message replication. In erasure coding based techniques messages are decomposed into smaller units of packets with redundancy, so that the original messages can be reconstructed even with the reception of a subset of the smaller units [5, 18].

In one of our previous studies we modeled the opportunistic network to possess two high level properties of Predictability and Connectedness [10]. By the application of predictability and connectedness information based on their past history, nodes can predict their future contact opportunities with certain level of confidence. Please refer [10] for the definition of predictability and connectedness information in opportunistic networks. In order to measure and analyze the applicability of predictability and connectedness information on opportunistically connected nodes, we have chosen an industrial command and control networking system where nodes generate a heterogeneous mix of data traffic throughout the operational time which has different bandwidth and forwarding requirements [10].

The application of a traditional ad-hoc routing protocol in modeling the system with the two high level properties and measuring the performance metrics reveals that the traditional ad-hoc network routing protocols operate memory less and do not utilize the underlying predictability

and connectedness information. Another reason is that because of frequent network partitions in the opportunistic networking environments many traditional routing techniques for MANETs will not work properly [2, 6]. Please refer [10] for more descriptive details on the simulation setup, simulation parameters and other in depth description of the system of this experimental study.

Lessons learned from previous studies and other works in the field have led the authors to design more effective routing schemes for opportunistic networks. In this work we present an adaptive, proactive routing protocol for opportunistic networking which can use the history of past contacts and utilize that information to determine the predictability and connectedness of future contacts. Each node uses these two information to choose the best forwarder node for data packets it possesses and forwards those packets to such selected nodes with high chances of delivery.

III. THE ADAPTIVE PROTOCOL

The adaptive routing protocol makes use of past history of opportunistic contacts to establish and exchange the neighborhood information in order to forward packets towards their destinations. Our basic idea for this new protocol is found on the following principle: Since each node has the ability to determine its predictability and connectedness information with its neighbors using its past history of contacts, nodes need not have to depend on any random exchanges and random probabilistic estimations to forward packets to their destinations. Instead, they can determine their expected future contacts with their neighbors with given levels of confidence, maintain this information in their connectivity tables and then propagate this information with whoever they meet including newer and older neighbors in the form of connectivity summary vectors. A snap shot of the connectivity table, which is maintained by each node is shown in Table I.

TABLE I

A SNAPSHOT OF A CONNECTIVITY TABLE MAINTAINED BY A NODE

Destination Node Number	First Choice	Connection Est. Time	Connection End time
1	4	T1s	T1e
2	3	T2s	T2e
4	4	T3s	T3e
9	9	T4s	T4e
10	2	T5s	T5e

Each row of the connectivity table, arranged in the increasing order of neighboring node numbers, contains the detail of the best forwarder node towards that node, next expected contact establishment time with the best forwarder node and the expected termination time of with this best forwarder node. If a node has never met another node in the past or have no chances of meeting a particular node, then it

maintains the information of the best node which might meet that particular node. By doing this, each node maintains a global view of the network connectivity even though it will not meet a given node in the future. Choosing the best node that can forward packets to its best neighboring nodes increases the chances of delivering packets towards their destination.

During opportunistic contacts, nodes first exchange their predictability and connectedness information of their intended neighbor contacts from their connectivity table as a connectivity summary vector. Upon receiving the connectivity summary vector from its neighbor, each node compares its own connectivity table against the received connectivity summary vector and updates its connectivity table information, so that its own connectivity table contains the latest information on best forwarders for future packet forwarding.

A. Neighborhood Establishment and Message Forwarding Algorithm

When each node receives predictability information from its neighbors in the form of a connectivity summary vector, it first updates its own connectivity table. For each destination, the connectivity table can also contain three best nodes that have the higher predictability value of meeting or forwarding to that destination node. The basic adaptive message forwarding algorithms executed by each node are given in the Algorithms described in Algorithm 1, Algorithm 2 and Algorithm 3.

Algorithm 1 Send (Connectivity Summary Table)

- 1: arrange predictability information in the minimum data structure.
 - 2: exchange connectivity summary table with met neighbours.
 - 3: wait for the next time interval to send if there is an update to the connectivity summary table.
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Algorithm 2 Receive (Connectivity Summary Table)

- 1: compare connectivity summary table with own connectivity table.
 - 2: if any of the received predicted contacts will occur before any of the stored contacts then,
 - 3: update that forwarding information with the newly received contact predictability.
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Algorithm 3 Receive (Data Packets)

- 1: check if the node itself is the intended destination of the packet.
- 2: if so then forward it to the upper layers.

- 3: if the packet is destined for another node, then do a look up at the connectivity table for the best node to forward, store it in the message queue and,
- 4: wait for a contact opportunity to occur with that node and forward the packet towards that node
- 5: if the node itself is the best node to forward the packet to the destination then store the packet in the message queue and wait till a contact occurs with the destination.

B. Message Exchange

Once a node pair establishes an opportunistic contact session, they first update their connectivity tables by mutually exchanging their connectivity summary vector. The basic steps in this process are: (1). exchange of the connectivity summary vector, (2) updating of their connectivity tables according to the received connectivity summary vector from the other node, (3) decide on which messages to forward to the other node, (4) forward the messages to the other node and also receive messages from the other node. We illustrate these steps in Figure 1.

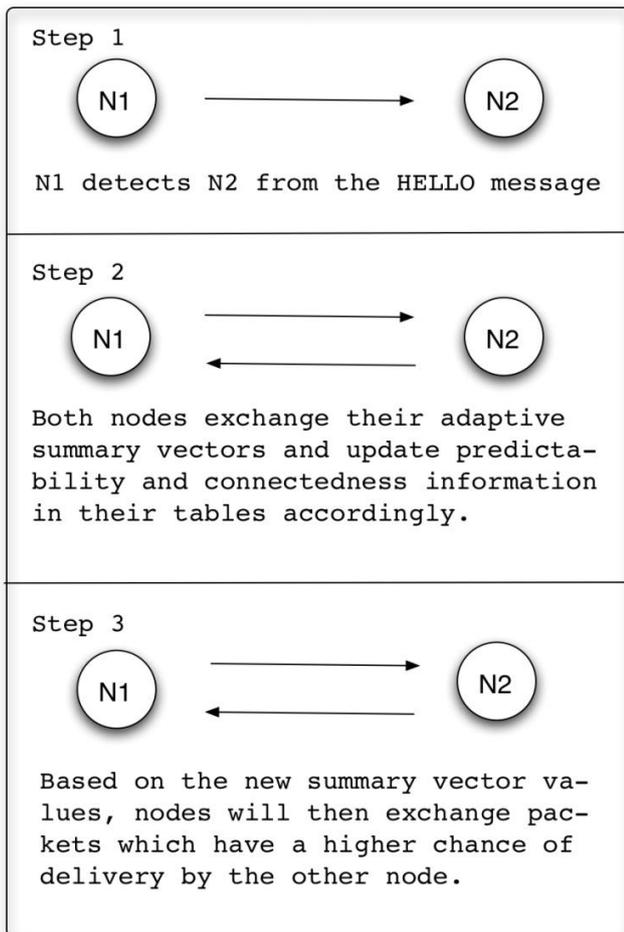


Fig. 1. Nodes exchange connectivity summary vectors periodically with each other.

During an opportunistic contact session, when a node receives a packet from another node and if the packet is destined for this node itself, then it passes the packet to the upper layer for processing. If that is not the case, then it will check for the best forwarder node for that packet. If the node itself is the best forwarder node, then it will store the packet

in its own queue and will wait for an opportunistic contact session with that destination node to happen.

If some other node is the best forwarder node then this node will store the packet in its own queue and will wait for an opportunistic contact session to happen with that best forwarder node.

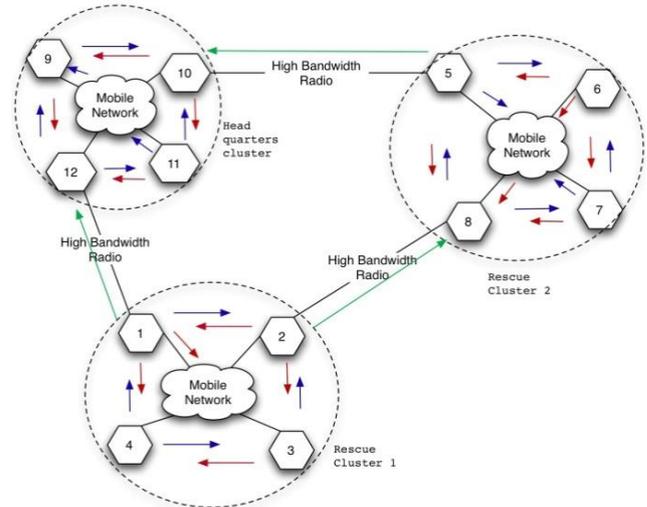


Fig. 2. The arrangement of 12 nodes into 3 clusters and their wireless contacts [10].

IV. EXPERIMENTAL SETUP

We use simulation based experimental studies to compare the performance variations between our adaptive protocol, the PROPHET routing protocol [13] and the Epidemic routing protocol [17]. We use the Jist/SWANS discrete event driven simulator [1] to model these protocols and carry out our experiments and collect statistics.

For our simulation based studies, we choose a scenario set up similar to the industrial command and control system as shown in Figure 2 and consider three clusters of nodes, where each cluster consists of four nodes. In this regard, we simulate the traffic generation according to the traffic requirements given in [10], and implement connectivity modeling, as described in [9], to model and simulate the intermittent connectivity in the network.

Since it has been observed that in typical rescue scenarios the rescue team members are expected to make regular contacts for every 3 to 5 minutes. In all our experimental studies we select the contact and inter-contact durations to vary in the time interval of 3 to 5 minutes and carryout our simulation based experiments. With the chosen time interval of 3 to 5 minutes, we considered two test cases for the adaptive protocol. In the first test case the predictability value is kept at 90% and the connectedness value is kept at 50%. In the second test case the predictability value is kept at 50% and the connectedness value is kept at 50%. For the PROPHET routing protocol, we consider the experiment set up parameters described in [14], and for the Epidemic routing protocol we model the protocol as described in [17].

A. Queuing and Forwarding Policies

An important resource in small mobile devices is the buffer space available. In the presence of intermittent connectivity and store, carry and forward paradigms, devices carry messages for their neighbors until they find a suitable forwarder or even until the ultimate destination is found. In addition to this, nodes themselves too generate traffic of data periodically with the hope that they will encounter a potential neighbor who can forward these packets to their destination. Since the buffer space can easily add up due to the frequent disconnections and longer inter-contact time intervals, buffer space should be maintained by adapting suitable buffer maintenance policies. Devices may purge messages that are destined for their neighbors which they do not expect to meet very soon. For our experimental studies we considered the following two queuing policies:

- Default (NOPO) - In this queuing policy, when the buffer is full, all future packets are simply dropped till there is any space to accommodate any arriving packets.
- MOFO (Drop the Most Forwarded message first) - In this queuing policy, the message that has been forwarded the most will be dropped when there is a congestion [14].
- SHLI (Drop the Shortest Life Time First) - This policy tries to drop the packet that has the shortest life time which is specified in the message [14].

When nodes meet each other in an intermittently connected fashion, they need to maximize the chances of forwarding packets from their buffers. Therefore they select an optimal node to forward the packet and have to decide which packets to forward towards the encountered node. If there are messages that are destined for the encountered node, then those messages are first forwarded to the encountered node irrespective of the forwarding policy. In our experiments we use the Greater predictability forwarding policy and in this forwarding policy, a message is forwarded to the other node if the contact predictability of this node is lesser than the encountered node for the given destination and exchanging summary vectors at the beginning of an opportunistic contact session helps each node to determine this information [14].

B. Performance Indicators

To measure system performance under different connectedness and predictability constraints and correctly identify system dependability for delivering content towards the intended recipients, we define and use the following performance indicators:

- Number of Messages Delivered: The number of messages that have been received at the destination. Calculating this value leads to the estimation of the message delivery percentage.
- Queuing Policies: The three different queuing policies described above have been chosen and the number of messages delivered by the protocols under these queuing policies is also considered.

- Larger Queue Size: Extending the queue size to some larger value to observe the number of messages delivered.

V. CASE STUDIES

A. Study1

In this study for each of the queuing policies mentioned above we have considered queue sizes of 20, 40, 60, 80 and 100 messages in each of the simulation run. With the considered simulation set up parameters we ran each of our simulation tests for a time period of six hours and have collected packet delivery statistics.

Results and Discussions:

In the sub Figures 3(a), 3(b) and 3(c) of Figure 3 we plot the message delivery count for each of the queuing policy separately. First of all, a general observation can be made from these three graphs with different queuing policies. It is obvious to note that the adaptive protocol outperforms the Epidemic and PRoPHET routing protocols in message delivery count in all cases with increasing queue sizes. This confirms our hypotheses of using the past history information in order to select the best future forwarder and thus achieves highest message delivery. For the two cases of the Adaptive protocol mentioned previously, the test case with the predictability value of 90% and the connectedness value of 50% performs better than the case with the predictability value of 50% and the connectedness value of 50% as we expected. Since the confidence level is higher in the first case, it is obvious that it achieves a higher value of message delivery count.

Surprisingly under the same testing conditions Epidemic routing protocol performs better than the PRoPHET routing protocol. The number of messages delivered by the Adaptive and the Epidemic protocols are considerably high when compared to the PRoPHET protocol.

Among the considered queuing policies, MOFO policy shows the best performance for the queue sizes considered when compared to the other two queuing policies. Since MOFO policy drops the most forwarded messages from its queue when there is congestion for buffer space, it ensures that the least forwarded messages get their chance to be forwarded and hence achieves the increasing number of messages delivered. When looked more closely, the just drop (NOPO) queuing policy performs equally with the SHLI policy. This is interesting to observe that since SHLI considers the time to live values of messages and even then could not achieve a better performance when compared to the just drop policy.

In order to analyze the effect of SHLI policy on different traffic types we considered the message delivery counts of type1, which is assumed to have the smallest Time To Live (TTL) value, and the type5, which is assumed to have the largest TTL value. Figure 4 shows the results of this case

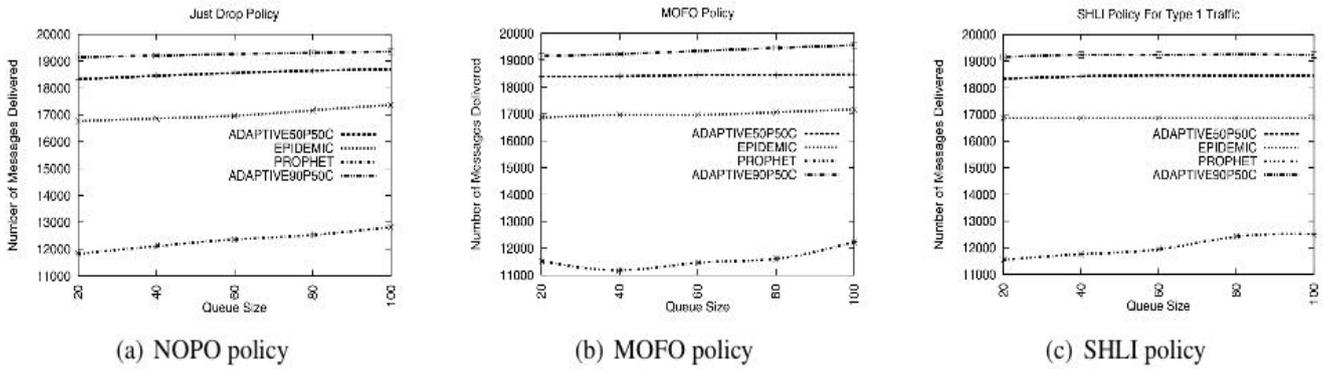


Figure 3. Message delivery count for traffic type 1 with Greater Predictability forwarding policy.

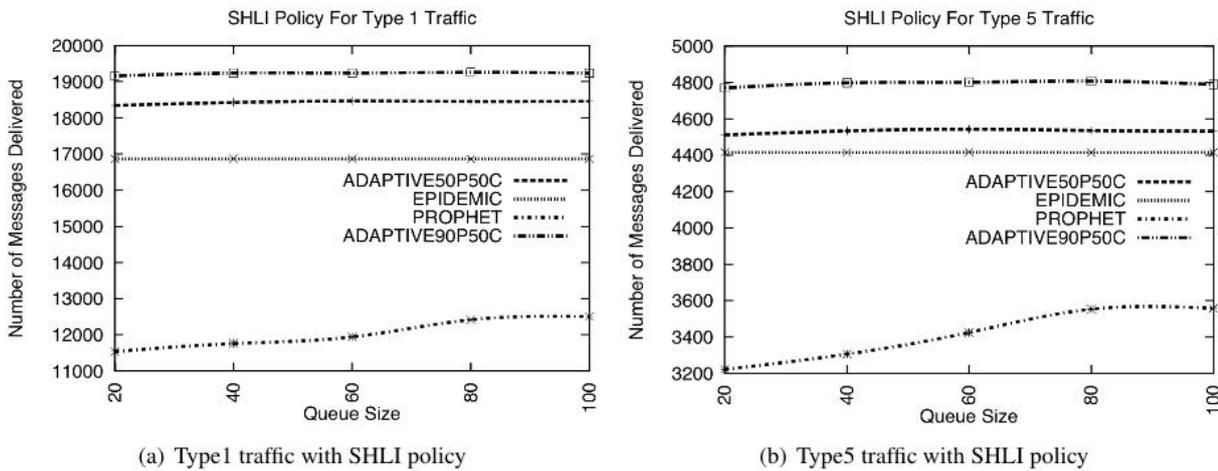


Figure 4. Message delivery count for traffic types 1 and 5 with SHLI Queueing policy and Greater Predictability forwarding policy.

study. Here we can observe that the larger TTL value of type5 enables the PROPHET protocol to show a performance increase with the increase of queue size, while the Epidemic routing protocol and the two cases of the Adaptive protocol show a similar behavior with the increase of TTL values. This clearly shows that our adaptive protocol not only achieves higher performance when compared to the other two protocols but also tries to deliver all different traffic types as quick as possible.

B. Study2

Having looked at the impact of increasing queue sizes and the greater predictability forwarding policy in the presence of varying connectedness and the predictability combinations, we are now interested in finding the effect of increasing the queue size to a very large number for all three routing protocols. For this case study we have considered the queue size of 500 messages since it provides an extremely large buffer space for messages and will allow the routing protocols to cache as much messages as possible.

Results and Discussion:

The three dimensional Figure 5 shows the message delivery count for this test with varying predictability and connectedness values along the x and the y axes respectively.

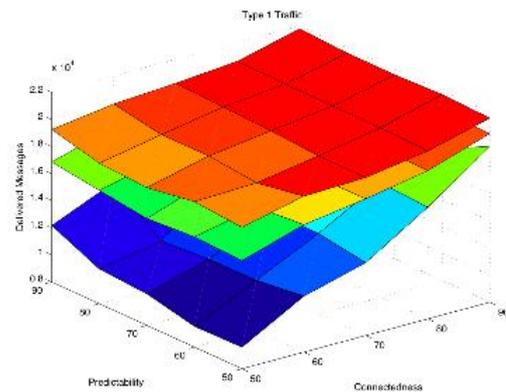


Figure 5. Message delivery count for the queue size of 500 messages.

In this figure we can clearly see that for all three protocols as the level of confidence increases along the x and the y axes, the number of successfully delivered messages also steadily increases. As it has already been observed in case study 1, the PROPHET protocol comparably shows the worst performance and the Epidemic protocol shows the second worst performance. Our adaptive protocol shows the best performance compared to the other two. Of course it is a

good sign that there is a tremendous increase in message delivery by increasing the queue size to such a larger value. But having a queue size of 500 messages is too expensive for small devices used in opportunistic networking and is not practically feasible at the moment. Since more and more extra storage space being added to such small devices because of the technological innovation and the price drop, allocating larger spaces for queues will soon be a reality.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we have described the design principles of a new adaptive protocol for opportunistic networking that can utilize the high level properties of opportunistic networking. We have implemented the adaptive protocol in the Jist/SWANS simulator and have measured its performance under different resource constrained scenarios. We have also implemented two well known protocols in the field and have measured the performance of them under the same testing environments. By considering various queuing policies for packet buffering and the greatest predictability forwarding policy we have shown that the new protocol outperforms the other two well known protocols currently used and the new protocol makes the best effort in delivering the maximum number of messages.

We have also found that the MOFO queuing policy combined with the greater predictability forwarding policy gives the maximum number of message delivery. Our experiments indicate the need to identify and utilize system resources in a best way to maximize the system performance.

We have also observed that increasing the queue size to some larger value also increases the message delivery ratio extensively. In this case too, our adaptive routing protocol outperforms the other two protocols. Even though there are serious concerns about allocating such higher buffer spaces for queues, in the near future having such larger queue sizes will be a reality.

One of our priorities in the list of future works is to investigate how nodes could use the adaptive protocol to avoid congestion at most centric nodes. We are also planning to put more effort in investigating how the protocol could be modified to consider messages with various priorities, sizes and other constraints.

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