Pocket Switched Networks Routing: A Survey

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***Abstract*—Pocket switch network (PSN) is a type of delay tolerant network which is a suitable process for areas where there is no Internet connection. Such networks are also called intermittently connected networks. PSN basically works on the basis of human mobility. Here, end-to-end connectivity is not assured. There are several routing protocols available in PSN. This is a new and very attractive research domain. Since its inception PSN has seen various proposals for efficient routing in an infrastructure-less scenarios where human mobility is the only way to transfer information. We have gathered simulated results from different papers and put them together in this study to understand the concept of the different protocols and compare them in terms of delivery ratio, latency average, number of forwarded messages, and number of messages dropped.**

Keywords: DTN, PSN, routing, epidemic, spray and wait, bubble rap .

I. Introduction

We have known TCP/IP as long as Internet has been around us. Although it has been around for so long there is a drawback of this protocol. If the end to end connectivity between two nodes is somehow lost or broken, this protocol fails to ensure reliability. To overcome that, the concept of nodes carrying the message around till it finds the destination itself or a node that is close to it, was introduced (also referred to as ”store-carry-forward” approach). Opportunistic Networks [31] also known as Pocket switch network (PSN) state that a human carrying a mobile phone can be both an end-user (destination) and a router (a relay node). It is one form of wireless communication network (independent of end to end connectivity between nodes) which is an instance of an older network commonly known as DTN (Delay Tolerant Network) [2]. On the other hand [20] has also categorized DTN as: flooding based, forwarding power based and social based. In flooding, messages are passed to everyone regardless of probability, whereas in forwarding a lot of metrics are taking into accord before routing. PSN is sort of network which cannot use traditional end to end connectivity or TCP/IP protocols, rather PSN uses the opportunistic meetings of human beings specifically for forwarding messages or packets whereas DTN takes into account all sorts of possible carriers including human beings, to forward data [22].It is suitable for circumstances which can lead to little or no Internet connection (for example: natural disasters, rural areas, deep forests, etc.). Since PSN is moderately a new field to explore and research, it can work without a specific infrastructure. Recent study shows that human based network connections are less inconsistent and long-termed than connections based solely on node mobility [4]. Therefore, for extreme situations social based DTN was more emphasized than any other form of DTN. For that reason PSN was introduced because it is the only form of DTN which concerns human behavior. Moreover, the current trend to opportunistically route in PSN is to base routing on human behavior and to take up a social approach which are less volatile and may lead to better routing [24]. In this paper, routing algorithms that are used in PSN are discussed and compared in terms of specific fields. All information has been taken from existing research papers, and to show our results on graphs for comparison, we generated our own data using the ONE simulator [9].

II. PSN routing algorithms

This section overviews most of the popular PSN routing algorithm in detail. Although this is a new research domain, but still there are quite a number of algorithms available that requires some survey.

A. Epidemic routing

The main idea of Epidemic routing [3] has a ”store-carry-forward” approach: nodes that can receive packets, store it into its buffer and carries that packet as it moves, passing the packet along to new nodes as they come into contact. Whenever the packet-carrying (source) node comes across a node that does not have a copy of that packet already, the source node is said to ”infect” this new node by passing the copy along and the newly infected node behaves the same when it comes into contact with other susceptible nodes (i.e., nodes without a packet).This routing protocol trades off performance by achieving minimum delivery delay with an increased usage of resources like transmission power, buffer size, bandwidth etc. There are some recovery schemes associated with this protocol [1]. Firstly, after the packet has been delivered to the destination node, a node can generate an ”anti-packet” within itself so that others nodes would not pass along the same packet again. This is known as the ”IMMUNE” recovery scheme. A more strict approach according to [1] is the forwarding of the ”anti-packet” among the infected nodes (which is known as the ”IMMUNE-TX” scheme) or among both the infected and susceptible nodes (which is known as the ”VACCINE” scheme) so that the number of copies sent are reduced. Both the "IMMUNE-TX" and "VACCINE" have similar buffer requirements.

B. First-Contact

The concept of first contact routing [4] involves only a single copy of the message available in the whole network. A node forwards the packet only when any single contact is available. If none of the contacts or paths are available, the message waits for one to be available. The source node passes along the copy of the message the first node it comes in contact with, making that node a relay node if it is not the destination itself. Once the message is passed along, the node deletes that message from its buffer. To make sure two nodes did not exchange the same message back and forth, a node forwards the message only to nodes who did not have it at all. Then after passing along and deleting the copy from its buffer it generates the "anti-packet" so that it does not get re-infected. This results in having a bad-delivery ratio, because the next node is selected randomly, which does not guarantee that this node has a higher probability of contacting the destination node than the previous, so no high yield. Moreover, even if the previous node had a greater chance to reach the destination node, it cannot be re-infected. This routing protocol only works if the source and the destination is only one hop away.

C. Bubble-rap

What is a community? It has been a vital concept of sociology and ecology for a long period of time. Community is a term used to assemble people who have common taste or maybe living in the same location [5]. This protocol is solely based on social behavior of humans. As in, it operates following a trend of popularity (connectivity). All the nodes in the network are grouped into a community and the node passes along a message based on the popularity 'RANK', usually if the next node is in a higher rank than the current one [4]. For this protocol to work, every node must belong to a community and have two rankings: local and global. The global ranking labels the node in the entire society whereas local ranking denotes the node's place in its own community [5]. If the destination node is within the community then the message forwarding will depend on a higher local ranking than the current node. Otherwise, the forwarding of the message will depend on a higher global ranking until it comes in contact with a node in the destination's community. From then on, higher local ranking is used to forward the message. By doing so, the probability of reaching the destination node will be greater. But what if one person belongs to multiple communities, that is, what if the communities overlap? It is vital to detect this feature. The K-clique method completes this purpose, and it is designed for binary graphs, so specifying the threshold of the edges is important. WNA (Weighted Network Analysis) can work on weighted graphs directly but cannot detect overlapping communities. We use both as per our needs.

D. Spray and wait

Spray and wait is another routing protocol for Pocket switched networks which was proposed in [10]. It is a modified version of the flooding based protocol. The first definition of Spray and wait is that it has two phases, which are as follows:

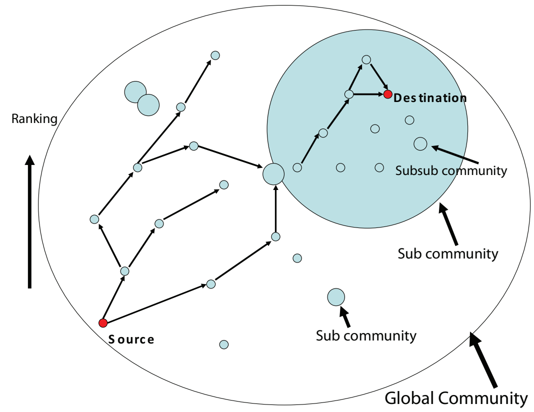

Fig. 1: Overall view of how the bubble rap works. [4].

1. Spray phase: every message that the source node carries, L number of copies of the message are initially forwarded by the source node and possibly other nodes receiving a copy - to L number of different "relays".

2. Wait phase: if the destination is not found in the spraying phase, each of the L nodes carrying a copy of the message forwards it only to its destination (performs direct transmission).

Epidemic routing and flooding has been morphed, resulting to Spray and Wait. Flooding keeps giving out copies of the message to every node it encounters until it reached its destination through nodes who received the copy or through directly passing. But Spray and wait makes L copies and sends them to L distinct nodes. Those nodes keep the copy until they meet the receiver. Here the number of message copies and how many to share remains open to discussion. In spray and wait, if there are L number of copies then any node A that has $n > 1$ message copies (source or relay), and encounters another node B (with no copies), it hands over half the amount ($n/2$) to B and keeps half for itself; when it is left with only one copy, it switches to direct transmission.

E. Lobby Influence

Lobby Influence was proposed in [6]. Lobby Influence works similar to Bubble Rap in the sense that it uses opportunistic ways to pass messages and they are both social based forwarding algorithm. It uses a modified version of bubble rap to enhance the delivery ratio and put less stress on the most popular node. The basis for Lobby Influence is derived from [7] who presented the metric known as Lobby Influence. They used diplomats dilemma [8] which states that a diplomat has a high influence in the society because he knows a lot of influential people of the society. Therefore a diplomat is as important as the actual influential person and he can reach them with minimum effort and low cost. The culmination of two criteria gives rise to the Lobby influence routing protocol. The two criteria are: Node Popularity (np) and Lobby Index (li). In summary Lobby Influence takes up

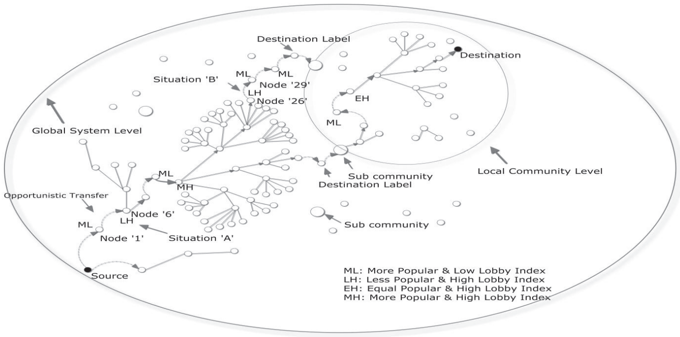

Fig. 2: Working principle of lobby influence. [6]

the ideas of Bubble Rap and Lobby Index algorithms and merges them together which results in the overcoming of the shortcomings of both the algorithms. The algorithm proposed by Khan et al may come across two situations on the basis of their algorithm:
1. Node Within a local community: In this situation if the destination node is in the local community and if the encountered node is part of the local community then local rank and lobby index is used to determine the forwarding decision. If lobby index or rank is higher than it forwards.
2. Node within the global system: In this situation the destination node is part of the global community. If the encountered node is part of the same community as the destination node then the message will be transferred and deleted from the node which it was sent from.

Khan et al simulated this algorithm using ONE (Opportunistic Networking Environment) [9] simulator which is designed for delay tolerant networks. In terms of message delivery and speed Lobby Influence outperformed Bubble Rap and Epidemic routing algorithms. According to [6], LI has a higher communication cost compared to BR but it significantly reduces load on most popular nodes in the network.

F. Prophet

Prophet algorithm is proposed in [13] which stands for Probabilistic Routing Protocol using History of Encounters and Transitivity. They have hugely relied on the repeated behavioral pattern which means that if a node visits a location several times, it is likely to visit that location again. Delivery Predictability is a probabilistic metric which was used by Lindgren et al which is defined as $P(a, b)$ at every node a, for each known destination b. This is used to understand the level of probability node a has to deliver messages to node b. Prophet is similar to epidemic routing in the sense that when two nodes meet they exchange messages as well as delivery predictability information stored at the nodes.They have calculated the delivery predictability of messages which is briefly described below:

Firstly the metric update is taken into consideration. The metric needs to be updated every time a node is encountered so that it is understood which nodes have a high delivery predictability. The following calculation has been used:

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

Secondly, the delivery predictability must age because if one node does not meet another certain node for a while then according to their hypothesis it is less likely that they will meet again. An aging constant, has been used in the following equation:

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

Thirdly, the delivery predictability has a transitive property. This basically means that if node A meets node B frequently and node B meets node C frequently then it is highly probable that a message given to C will be delivered to A. They have used a scaling constant in the following equation:

$$P_{a,c} = P_{(a,c)old} + (1 + P_{(a,c)old} \times P_{a,c} \times P_{b,c}) \times \beta \tag{3}$$

Finally the forwarding strategy is pretty simple and straight forward. When two nodes meet if the delivery predictability of the destination of the message is higher at the encountered node then the message is passed.

G. Friendship-based routing algorithm

In PSN, since the people are considered as nodes, this algorithm involves making the decision based on the friendship between two nodes (people). This algorithm introduced a new metric called social pressure metric (SPM), taking into account different sides of social behavior of people. For two people to be considered friends of each other, they have to meet up frequently, make regular and long-lasting contact. In order to ease up the challenges faced during discontinuous end-to-end connectivity, [14] have emphasized on three components of friendship: durability, high frequency and regularity. Friendships can strong and weak. Two nodes can be good friends directly, other scenarios include two nodes having no direct friendship among them but has a very strong mutual friend. In that case, they can be considered as indirect close friends. To label such indirect connections, [14] suggests to use conditional SPM between. And when it comes to direct friendships, every node can identify them using their own contact history.

This algorithm follows the following forwarding strategy: if node A has to forward a message to node B, and meets node C in the middle, A will forward the packet to C if and only if C has a stronger friendship with B than A in the current time period. But in [14], it was also mentioned that even if C has a better connection to B than A but does not include B in its current time period (time taken to form a community), A will not forward it to C.

III. Result Comparisons

This section compares results of various routing algorithms for PSN. The comparisons are based on simulations and comparisons from other research papers. The references will be mentioned accordingly.

A. Prophet vs Epidemic:

To start with, we can see according to Lindgren [13], as the queue size increases the average delivery rates of PROPHET is always above the curve for epidemic routing.

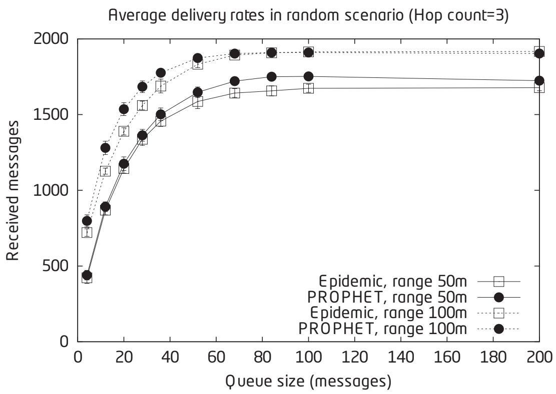

Fig. 3: Average Delivery Rate in random scenario (Hop Count=3). [13]

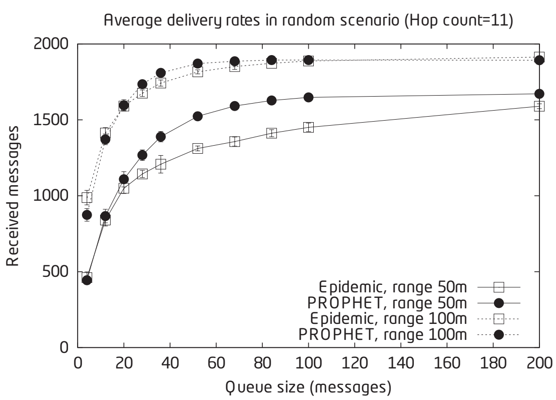

Fig. 4: Average Delivery Rate in random scenario (Hop Count=11) [13]

Secondly, we have the graphs for the average delays in random scenario where upto a certain queue size the delay in PROPHET is more than Epidemic but as the queue size increases, Epidemic tends to have higher delays than PROPHET.

Also in fig7 and 8 the average delivery rates (in community scenario) is shown as a comparison with Epidemic. It can be seen that by all accounts as the queue size increases the number of received messages is always more for PROPHET by a significant amount. Hence, we can conclude by saying that PROPHET is better in delivery rates (both in random scenario and community scenario), and also having lower delays when in comparison to Epidemic Routing.

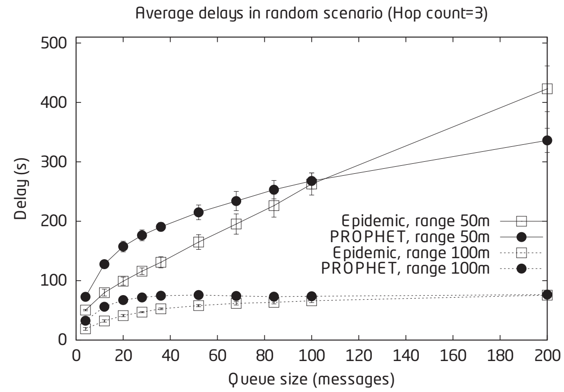

Fig. 5: Average Delays in random scenario (Hop count=3). [13]

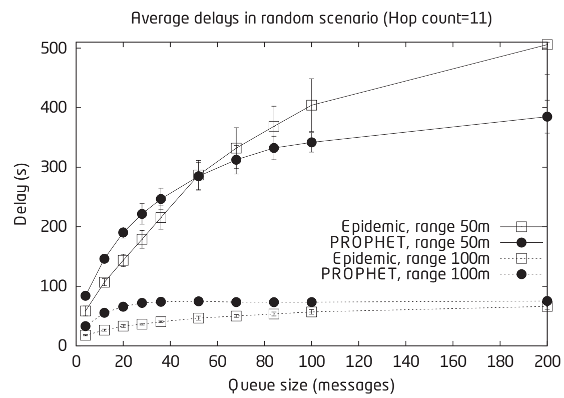

Fig. 6: Average Delays in random scenario (Hop count=11). [13]

B. Lobby Influence vs Epidemic vs Bubble Rap

This experiment was done in [6]. They used a total of ten experiments on 24 Computers. The code for this comparisons is provided in [9]. The algorithms were measured against three metrics: 1. Message Delivery: How many packets arrive at destination 2. Delays: How quickly packets arrive at the destination 3. Forwarded messages: the cost in terms of number of exchanged messages, in other words utilization of resources.

1. Message delivery: In fig9 it can be seen that Lobby influence has the highest received messages as the queue size increases at any given point during the course of the experiment. Epidemic on the other hand performs worse than Bubble rap.

2. Delays: The latency average is measured in seconds in fig10. Epidemic has the highest latency because most of the nodes exhaust their queue size by accepting unnecessary messages due to lack of message forwarding criteria and as a result more messages are dropped. Here we see that Lobby Influence has the best Latency. This means that packets or messages are being delivered faster than BR and Epidemic.

3. Forwarded messages: The amount of messages forwarded

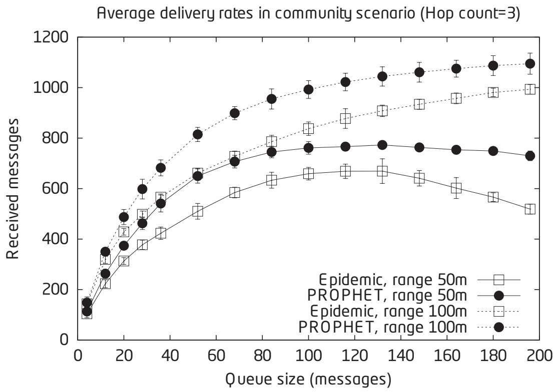

Fig. 7: Average Delivery Rate in random scenario (Hop Count=3) [13]

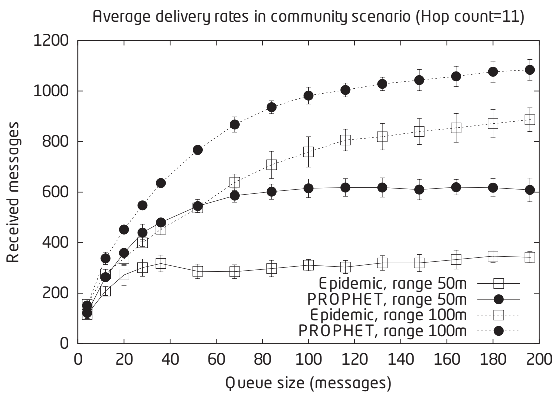

Fig. 8: Average Delay Rate in random scenario (Hop Count=11) [13]

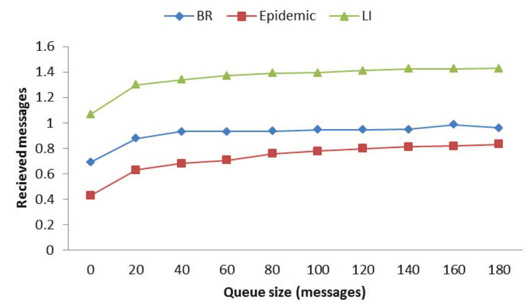

Fig. 9: Average Received Messages in Bubble Rap, Epidemic and Lobby Influence. [6]

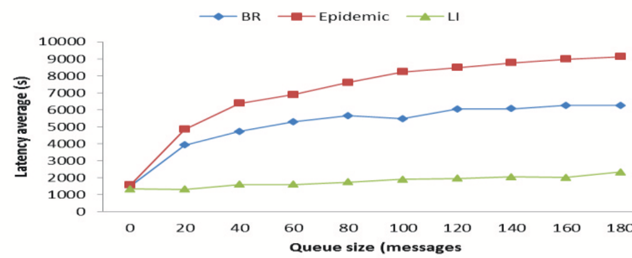

Fig. 10: Latency average in Bubble Rap, Epidemic and Lobby Influence. [6]

by Epidemic is rightfully at a higher level than the other algorithms because of the way epidemic works. Epidemic basically gives those messages, the encountered node does not have, to every node it meets. Therefore it passes messages very frequently when compared to the others. Bubble rap only gives messages based on one criteria: rankings. On the other hand Lobby Influence gives the messages according to two criteria's: rankings and Lobby influence so probable message sharing is more. Although bubble rap has the best figures here it can be said that due to the delivery ratio and lower delay lobby influence is better.

C. Spray and wait vs other algorithms:

Spyropoulos et al proposed the spray and wait and simulated this using a custom event-driven simulator and evaluated them using a variety of mobility models and under contention. In this scenario a network size of $200x200$ has been used. The number of nodes M and the transmission range K has been varied to compare the performances of several routing algorithms. A lot of combinations have been used from very sparse, highly disconnected networks to very closely spaced networks. In this simulation the following algorithms have been considered: (1) Epidemic routing (2) Randomized flooding (3) Utility-based routing (4) Spray and Wait (5) Seek and Focus single-copy routing (6) Oracle-based Optimal routing

In figure12 and13 the number of transmissions have been tested. Here, the less the number of transactions, the better the algorithm. That means, that the less the number of transmissions the less amount of resources have been used of a single node. It is evident from the graph that with varied transmission range K values and $M = 100$ and $M = 200$ that spray and wait has the smallest transmissions and epidemic has the highest number of transmissions. Therefore we can safely assume that spray and wait in comparison to the mentioned algorithms is better at resource utilization.

In scenario fig14 and 15, the delivery delay has been monitored using different values for K and M. It can be observed that spray and wait (both versions where $L = 10, 16, 20, 32$), has the lowest delivery delay among the mentioned algorithms.

Therefore considering all the aspects we can say that comparing Spray and wait with Epidemic, it is better in all aspects like delivery delay and number of transmissions.

The results have been summarized in Table I.

One of the challenging issues in PSN is network congestion (due to flooding). In order to obtain improved results in this area, we can look into how the nodes take forwarding decisions. In [32], they talk about a heuristic function based on the hop count, that helps the message-carrying nodes take forwarding decisions. That is done by using the information carried by the packets traveling through the network. Other

TABLE I: Comparison between different Algorithms .

	Epidemic	First-Contact	Spray and wait	Prophet	Lobby Influence	Bubble Rap
Messages delivered	Moderately Low	Very low	Low	High	Very High	Moderately High
Messages dropped	Very High	Very Low	Moderately High	High	Moderately Low	Low
Messages forwarded	Poor	Excellent	Fair	Adequate	Good	Very Good
Average Latency	Fair	Poor	Good	Adequate	Very Good	Excellent

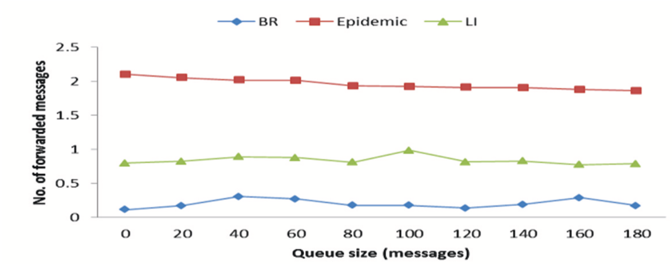

Fig. 11: Number of forwarded messages in Bubble Rap, Epidemic and Lobby Influence. [6]

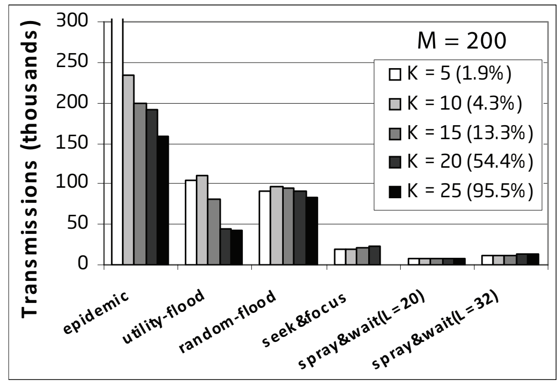

Fig. 13: Transmissions as a function of number of nodes M=200 and transmission range K. [1]

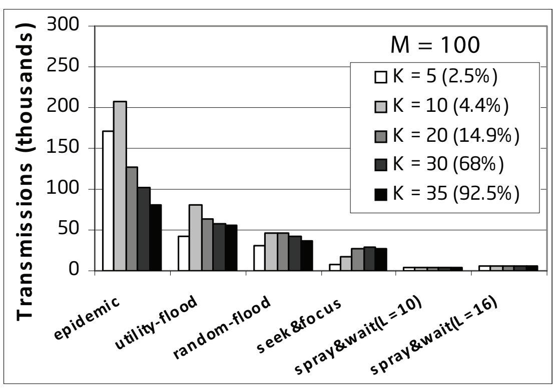

Fig. 12: Transmissions as a function of number of nodes M=100 and transmission range K. [1]

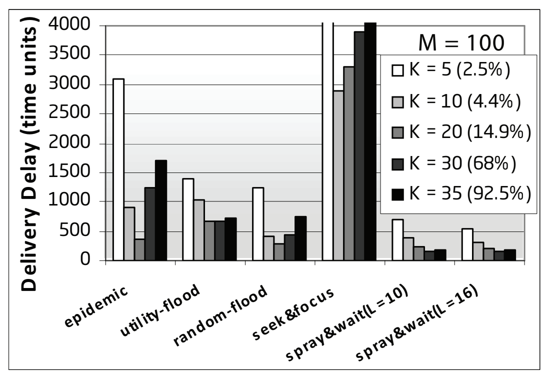

Fig. 14: Delivery Delay as a function of number of nodes M=100 and transmission range K. [1]

forwarding schemes include the direction entropy-based forwarding scheme (DEFS) [33], which involve emphasizing only on those nodes that are more prone to travel to different locations to forward the messages to the destination nodes. In addition to this, since the nodes are always moving, the topology of the whole network is a bit difficult to keep track of. A node will always have to either search for the destination, decide to stop or send a response back. Even if we do succeed in keeping track, loss of resources (like battery) has to be taken into account. In [34], an optimal search was suggested where there are three parts: static search in which the search depth is set at the start of a query, dynamic search in which the depth is determined locally during the forwarding of messages, and learning dynamic search which influences the observation to determine whether the content is suitable for the query or not.

IV. Future Research Scope:

For 2017 the number of mobile phone users is forecasted to reach 4.77 billion. So we can assume that PSN will be very useful and popular in the near future. If we can implement PSN using all the 4.77 billion cell phones we can have almost an infallible network. There is still a lot of work that needs to be done to implement pocket switched networks. Work on reliability of the messages and to control the huge amount of data (which can lead to congestion in the network) is done in [19] but they are based on MANETS, which can easily be implemented on PSNs. In the near future, space programs may need to implement PSNs which is still open for research as mentioned in [21]. Work is done in [27], [28], [29] showing that Wi-Fi connections of the cell phones may be used to

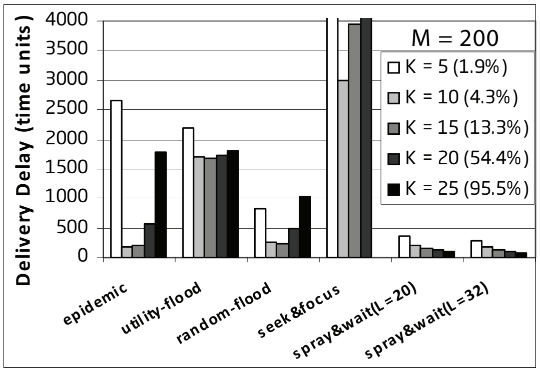

Fig. 15: Delivery Delay as a function of number of nodes M=200 and transmission range K. [1]

create a pocket switched network to send and receive messages from a distant location. There is still room for improvement in this and the routing protocols for better delivery ratio and lower drop rate. A very big issue in PSN is: there is very little or almost no work done in the security measures. One of the attacks is known as flood attacks which is an issue for DTNs mostly, but may also be an issue in PSNs. In [23] they address this issue by implementing rate limiting [30] but, then again, this is for DTNs. The basic idea is very simple, which is to limit the source node to transmitting a ceiling value of messages. Therefore in the future, the security of PSN may still be researched upon to create a full-proof system of passing messages.

V. Application Domain:

The very first application domains that can be noticed are the areas where there are no infrastructures for any end to end connectivity. PSN should be normally applied using cell phones. For example, in a dense forest this can be used since very few people travel through there. If everyone has PSN enabled cell phones then data collection and sharing of data would be very easy (since no connection is required). The people living in very distant rural areas may use PSNs as non-interactive internet [25]. Secondly the work of [15] on the reindeer herd of the Swedish Lapland's is mentionable. They have used DTNs, but they could also use PSN which would perform the same. Thirdly, NASA has a lot of satellites in space and using that we get weather information, short/long range environmental prediction, global air current prediction, and also predicting natural hazards according to [16].A way has been searched such that satellites can share information. In their paper, they have discussed the sharing of such data for earth observing satellites that will support the next generation of space exploration. In [21] they suggest that satellites, which can be subjected to tolerate delays and where long space and satellite communications is needed, we can use DTN. Moreover, they have pointed out that DTN is the way to go to support future space programs and deep space communication which is also supported by [25], [26]. Again, since PSN is a part of DTN this can also be applied here. Another application domain is collecting information on animal behavior, ecology, habitat preference of animals, physiology and movement patterns [17]. The use of PSN may greatly improve efficiency. We can use the work done at [18] to know the weather information throughout a park. The military may also use PSN specifically to gather information and to transmit messages about their environment among their own respective sides. Since in a war zone there is absolutely no internet and no cellular networks they may use PSNs [25], [26]. Lastly, in extreme situations like natural disasters, we can use PSN in rescue missions. In a disaster recovery scene we can use PSN to find victims and gather vital information about the rescue workers and also to station them in an efficient manner [21], [25], [26].

VI. Conclusion

In this paper we have provided a brief literature review of several routing protocols that are applied on pocket switched networks, which is a sub division of Delay Tolerant Networks. Through our observation of the literature we have come up with the conclusion that Lobby Influence outperforms all the other routing protocols in terms of delay time, the drop rate, the number of messages delivered and the number of forwarded messages. The results of several simulations have been mentioned and it is evident that among the many famous routing protocols like epidemic, bubble, PROPHET that the Lobby Influence routing protocol performs the best. But there are still works that can be done here to improve the delivery ratio and the delay. The application domain of Pocket Switched Networks have also been suggested and we have also suggested some areas of PSN which are still open for research and can progress this field further.

In a world with 4.77 billion cell phones roaming around, imagine each cell phone turned into a mobile router. Internet, as we know it, will change forever. Even if every static router on earth goes down we will still be able to get messages to and from others throughout this huge network. We will never be disconnected.

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