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Resilient Connectivity: Leveraging Pocket Switched Networks for Post-Disaster Communication

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Abstract: The Pocket Switched Network (PSN) serves as a communication paradigm suitable for scenarios where the conventional network infrastructure is either damaged or intermittently available. Positioned within the domain of Delay-Tolerant Networks (DTN), PSN operates without a fixed infrastructure and leverages human mobility patterns to determine optimal routing. Because of the damaged communication infrastructure, this communication concept finds practical application in areas affected by natural catastrophes. In this research, a thorough analysis of several routing algorithms used in Pocket Switched Networks (PSN) is conducted. It also presents a paradigm based on PSN concepts that is intended to support resilient communication in post-disaster situations.

Keywords: *PSN, DTN, Mobility pattern, Communication, Post-Disaster*

1. Introduction

Electronic Over the decade, Internet has been connecting different communicating devices worldwide and plays a vital role for an end-to-end data transfer with the help of network protocol. TCP/IP (Transmission Control Protocol/Internet Protocol) is the most used network protocol. TCP/IP can transfer end-to-end data more efficiently and reliably when the connectivity is robust. But in some scenarios, when the end-to-end connectivity is broken or intermittent, TCP/IP may not work correctly. In worst cases, it can completely fail to transfer data. This problem occurs mainly in remote areas or villages that lack basic infrastructure to support the Internet or regions affected by natural disasters. Pocket Switched Network (PSN) can be an alternative in such circumstances. PSN are independent of end-to-end connectivity, which means it does not require any specific infrastructure for effective data transfer. PSN falls into the category of another older network known as Intermittently-Connected Mobile Ad-hoc Networks (ICMANET), which is also popularly known as Delay Tolerant Network. ICMANET/DTN can be effectively used for end to end data transfer in the field of wireless communication [1]. This type of network can be deployed for the challenging environment, where nodes are intermittent or experiencing a lack of continuous connectivity. Bandwidth limitations, error probability, latency, node longevity, or path stability are the characteristics of a challenged network. In the case of architectural design space, DTN considers the different types of choices such as hop to hop reliability and security, named and address-based routing, routing of messages over a partially or intermittently connected network rather than the fully connected network. DTN can be applicable for interoperability between and among challenged networks which mainly work based on an abstraction of message switching. The clusters of messages are known as a bundle. Bundle forwarder or DTN gateway especially assign for handling bundle. PSN (Pocket Switched Network) falls into the category of DTN. Information carriers are the main characteristic to differentiate between PSN and DTN. PSN employs human beings for data forwarding, while DTN utilizes any possible carrier, including human beings, to disseminate data. PSN uses the knowledge of the social characteristics of human society. Human related networks are less volatile and stable than simple node mobility-based networks. PSN is very effective for making better routing decisions for a network with a human mobility pattern. This networking concept is very effective for heterogeneous networks. PSN employs a store-carry-forward mechanism as it experiences a lack of continuous network connectivity and enables data transfer when mobile nodes are only intermittently connected, or the connection is broken. According to this mechanism, intermediate nodes are used to carry data packets. They receive it and forward it to the next node when encountered. PSN uses human mobility to distribute data from source to destination [2,3,4]. The node's popularity can be considered an effective measure for successful data transfer. PSN does not require any proper infrastructure for successful data transmission, so it can be applicable to rural areas or areas affected by natural disasters where the communication infrastructure is intermittent or complete

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broken. Mobile phones, personal digital assistances (PDAs) and laptops etc. and other communicating mobile devices [5] carried by the human in a restricted physical space (i.e. conferences, around office spaces and in case of social communications) with a large number of nodes and contact density. In this scenario, the contact patterns are not fixed. In such a situation, PSN can work effectively [6,7] in which both mobility and multihop forwarding can be supported for communication. In this paper, section I, II, III, IV and V represents an introduction to PSN, respectively, routing algorithms for PSN, Proposed model for post-disaster communication, Challenges for implementing this proposed model and conclusion.

2. Routing Algorithms For PSN

PSN networking, a communication paradigm, was proposed by Pan Hui et al. [8], representing the reality a network faces because of the mobility of nodes. Let us consider that we have a set of nodes P = {A, B, C… N} and set of data packets M = {m_1, m_2,……m_n} . Suppose node A wants

to transmit message m_1 to node C's desired destination. When node A encounters another node, it will first check whether the encountered node is the desired destination or not. If the encountered node is the destination, the packet will be forwarded. Otherwise, it will carry the packet until the desired goal is met. Each node has a capacity C for maintaining the data packets. Direct Delivery Routing [9] is the simplest way of transmitting messages or chunks from source to destination. This protocol delivers messages only when the source node encounters the desired destination node. Direct delivery routing necessitates communication between the origin and destination nodes. It's a simple approach for routing. First Contact Routing [9] belongs to the category of The direct pass algorithm. According to this technique, the source node sends a message to any encountered node. Any node that comes into contact with the originating node receives this message and becomes the relay node. It improves the chances of successful message delivery and the bandwidth available. This routing approach saves space by reducing the amount of stored data.

When the message contacts the source node or relay node carrying the messages, it is delivered to its desired destination.

Spyropoulos et al. [10] represent algorithms that mainly follow a single-copy-based scheme. According to this algorithm, a node named “custodian” carries a copy of the message to deliver it to the desired destination. When the current custodian forwards the message to the new custodian, it does not generate multiple copies of the same message. This criterion increases the robustness of the algorithm. According to this scheme, the source node creates a message and holds it until the desired destination is encountered. A message can be sent effectively with just one transmission, which is the advantage of this algorithm. However, it may result in unanticipated latency when delivering a message.

Epidemic routing [11] follows the concept of flooding based protocol. The main objective of this protocol is to reduce the amount of consumption of resources and maximize the amount of successful message delivery to its desired destination. This protocol mainly works on message replication, and messages are distributed to each possible node in the network. The epidemic routing algorithm is designed to spread messages through intermittently connected networks. According to this algorithm, each node has a buffer to store messages and maintain a hash table representing the list of messages. Each host also has a summary vector (a bit vector) that indicates which entities in their localhost is set. Suppose node A and Node B have come into contact for message transmission, and a session has been initiated named anti-entropy session. Node A transmits its summary vector V_A to node B in the first step. Next, node B performs a logical AND operation between the negation of summary vector of and V_A. Then node B determines the set difference between the messages buffer at A and the messages buffer at B. Then node B transmits a vector requesting messages from A. Finally, A forwards the requested messages to B. This protocol minimizes the latency of message delivery. A different version of the Epidemic routing algorithms are also [12,13] proposed. This algorithm reduces resource consumption and maximizes the successful delivery of the message. In terms of traffic congestion and energy, it reduces overhead by considering different constraints such as time limit, maximum hop count, and message forwarding probability. It requires no prior knowledge about the network. Flooding based protocol can also follow tree structures [14].

Here, making copies of the message and ensuring the number of copies of the message is an important issue. So, message replication occurs that results in high overhead and consume more energy.

Spray and Wait [15] routing protocol is a flooding-based routing algorithm. Under all conditions, this algorithm performs significantly fewer transmission than other flooding-based routing algorithms, achieving a delivery delay almost close to the optimal, highly saleable. This algorithm works on two different phases: The first phase is called the spray phase, in which the source node

generates several messages and spray them to that number of the distinct node defined as a relay node. In the waiting phase, after spreading the messages, if the destination node is not met, the nodes carrying the message copy perform direct transmission. Spray and wait routing protocol sprays several messages and wait until it completes their desired destination.

PROPHET [16] routing protocol is a probabilistic model-based protocol mainly proposed for intermittently connected networks where the communication path is not predefined. According to this algorithm, when two nodes meet, the source node transmits the message to the other node if the encountered node's delivery predictability is higher than the source node's. The first node does not delete the message if there is sufficient buffer space. When a new message arrives and the buffers are not available, a message must be dropped using the queue (First in and first out) concept. If a node visits the same place several times, it increases the probability of seeing the same place in the future. In this protocol individual node uses a metric named probabilistic metric. This metric assists the node to deliver messages to a reliable node. This delivery predictability can be calculated using the following equation (1) \ref{a}. Here node i and j meet one another, and their elapsed time unit is k.

$$p_{i,j}(k+1) = \left(1 - p_{i,j}J(k)\right) * p_0 + p_{i,j}\,(k) \qquad (1)$$

This algorithm enhances the delivery probability of massages to their desired destination. It has lower overhead, low consumption of storage space, reduced power consumption and increased chance of delivering the message to its desired destination. But it may increase the average delay in delivering a message from the source node to the destination node. Boudguig, M. et al. propose another technique [17], a probabilistic method for managing bandwidth and message delivery resources. This algorithm is mainly an extension of PROPHET [16]. According to this algorithm, messages are exchanged between one node to another by considering higher delivery predictability than the other mobile nodes. This approach is based on the predictability concept to reduce latency on message delivery and the number of message drops. To improve the component indicated above, an improvement factor is inserted in the probability calculation equation of PROPHET in thisway. MaxProp [18]routing protocol is mainly based on prioritizing messages in the buffer. This priority is specified based on the message transmission schedule and the scheduled packets dropped. This algorithm calculates the priority of messages by considering hop count value H_p and threshold value Th.

If $Hp \;>=\; Th$

Packet is deleted first from the lower rank.

delivery probability is set higher. Else Packet is transmitted first from higher rank. Delivery probability is set higher.

The above considerations increase the rate of packet delivery and reduce latency.

Plankton [19]is mainly worked to reduce the overhead of nodes to utilize replica control by predicting reliable contact. To expect a reliable connection, plankton considers two fundamental ideas, and they are respectively classifying the communication link into a strong link or weak link. Successful message delivery specifies this classification. An associative relationship defines strong connections that are observed a different time. To deliver a message m, an initial replica quota Q is assigned (represents the maximum delivery probability of messages) along with a target delivery probability. When the initial replica quota Q is fully utilized, then Q replicas are transferred into Q relays, and it will help the message m to gain maximum delivery probability. The source node knows the relay nodes and their delivery probability to set Q appropriately. This algorithm controls replicas that ultimately reduce overhead and increase delivery probability. It also adjusts replica quota and delivery probability dynamically.

PNGP [20] mainly considers the popularity of nodes belonging to a community for routing decisions. According to this algorithm, transmission happens only when the destination community is detected and the encountered node is popular. It is delivered if the encountered node is the destination node. Otherwise, it floods. As a result, the delivery ratio becomes high. This algorithm considers three assumptions: each node belongs to a community, and other nodes can observe it, each node can monitor the destination community of each message, and each community contains up to 6 nodes. For intra -communication, this algorithm uses the flooding concept. For intercommunication, it will identify the destination node of the message and then find whether the destination node is the most popular node within its community or not. If it is true, then the message is transmitted. This algorithm performs better in transmission cost, average delay and delivery ratio.

Bubble Rap [21] considers social behaviors for making a forwarding decision. Each node belongs to a community, and messages are transmitted among the node by considering their popularity named RANK [22]. In Bubble Rap, two such RANK is regarded as a local rank representing the popularity of a node within its community. And another is Global Rank, which means the popularity of a node within the whole network [23]. For intra-communication and inter-communication, a node's local ranking and global ranking are considered, respectively, which means the message is forwarded to an encountered node of higher rank until it reaches the desired destination.

Lobby influence [24] also uses a social network-based concept. This algorithm also considers local and global rank [21]. A lobby index is also considered here for making a forwarding decision. The strength of the relationship with the neighbor node is regarded as the lobby index. This algorithm finds three assumptions for making forwarding decisions. Each node must belong

to a community, each node has a local and global rank (a node may be multiple local rank and label), and each node must have a Lobby index. This local and global rank assist in identifying local and global centrality, which mainly focus on betweenness centrality values to enhance the algorithm's performance [25]. Lobby increases the probability of message delivery and reduces the overhead of nodes.

EER [26] considers the forwarding capability of nodes in different communities for effective data forwarding. It also finds resource limitations of PSN devices (memory space limitation, computational power) [27] and the TTL [28] of the data packets for making a forwarding decision. EER considers that each node must belong to at least one community. Each node has its forwarding power measured by the participation of a node in the forwarding process. The global popularity is also considered, and EER considers an epoch time of 7 days. For intra-communication, the forwarding power of a node is calculated by the following equation where g(x, y, t) =1 if an interaction occurs between nodes x and y in the time interval t, and otherwise, it becomes 0. Here c means the community.

$$\forall(c,x)FP_{(x)} = \sum y\ (x,y)\exists C_x \sum_{t-1}^{t} \mathrm{g}(\mathrm{x},\mathrm{y},\mathrm{t}) \quad (2)$$

And for intercommunication the forwarding power of a node is calculated by the following equation (4) and (5) respectively. For equation (5) EER consider

$$c' \neq c(x) \quad (3)$$

$$\forall(x)GP_{(x)} = \sum y \nexists C(x) \sum g(x,y,t)tt = 0 \quad (4)$$

$$\forall(c',x)FP_{(x)} = \sum y \exists C'(x) \sum g(x,y,t)tt = 0 \quad (5)$$

This algorithm performs better in the delivery ratio (measured by the ratio of a number of successfully delivered messages to a total number of the message), transmission cost (measured by the transmission of a message from hop to hop) and delay (measured by the difference of time between a message generation and successful delivery of message) compared to another routing algorithm.

3. Proposed Model For Post Disaster Communication

Natural disasters have a significant impact on human activities and traditional network infrastructure. The communication infrastructure has damaged as a result of the disaster. Continuous connectivity is complex in this situation. Natural disasters are beyond human control, yet the consequences of disasters can be mitigated. In such a situation, Pocket Switched Network (PSN) provides an effective alternative for postdisaster communication to conduct rescue and relief operations effectively. In this work, we propose a model for establishing post-disaster communication.

A. Clustering the disaster affected area

Firstly we have to divide the disaster-affected area into the different clustered neighborhoods for detecting communities as most of the algorithm in PSN is developed in a flat approach. Clustering may provide a better result for an extensive network. The clustering approach increases system capacity as it reuses resources. It also limits the number of information transmissions during routing as routing information is shared with only other cluster gateway. In order to achieve the scalability of a network, clustering is necessary. It also helps to reduce the overhead of nodes. Louvain algorithm [29] can be used to detect communities among nodes. Clustering approaches can be useful to unfold large networks into different communities. This algorithm identifies high modularity partitions of a large network. This algorithm unfolds a large network into a complete hierarchical structure. Louvain algorithm mainly works in two different phases. In the first phase, this algorithm considers each node as a weighted node. Initially, each node forms an individual community. After that, for each node X, consider its neighbours Y and calculate the gain of modularity (Gm). Node X will be placed in the community of Y, if Y has more gain of modularity than X. The gain of modularity of a node is calculated by using equation 6.

$$G_m = \sum_i + \frac{k_{x,i}}{2A} - \left(\sum_{total} + \frac{k_x^2}{2A} + \left[\frac{\sum_i}{2A} - \frac{\sum_{total}{}^2}{2A} - \frac{k_x^2}{2A}\right]\right) \quad (6)$$

Let us consider that C is the community. ∑i is the sum of the weight of the link, ∑total is the total of the weights of node - to- node linkages. Within the community, C. k_x, is the sum of the weights of the links from node x to nodes in C, and A is the sum of the weights of all the links in the network. In the second phase, this algorithm builds a new network among the communities found in the first phase. This network is formed by calculating the sum of the weight of the links between nodes. After each pass, the number of communities decreases by combining both phases. This algorithm builds the hierarchical structure of communities, as each pass creates communities of communities. The number of passes determines the height of the hierarchy of the communities. In this paper, we provide a model for post-disaster communications, proposing that a community clustering strategy is essential for better results when dealing with a sizeable disaster-affected area.

B. Defining mobility pattern

Human mobility plays a crucial role in PSN. Mobility gives rise to new localized opportunities. User mobility also increases the use of network bandwidth as a large amount of data needs to be carried around the network. The probability of node mobility is measured by using different mobility models. The random waypoint model [30] is a model for detecting the mobility pattern of nodes. This model randomly chooses a waypoint (destination) and moves towards it. Different approaches to this model are the random-direction model [31] and the random-border model [32]. Clustered-mobility [33] is another mobility model that follows random based movement where the attraction of a point depends on the nodes encountered nearby. We can use clustered mobility model (CMM) [34] in the case of post-disaster communication because it follows random based movement, which means each node tend to move closer to the highest connected nodes. This algorithm uses a new graph model named a scale-free wireless network (SFWN) [35], with no scale. Actually, within the network, each node is connected with other nodes. The most popular nodes within the network are called a hub, which is connected with hundred or thousand or a large number of nodes. One of the main advantages of this type of network is robustness. CMM is mainly worked in two different phases, which are named as respectively initial layout and mobility. So firstly, let us consider that, sub_i, is a subarea of a network and sub_{tot} ,is the total number of the subarea . n, is the number of nodes in the subarea, and the probability of choosing the subarea as a destination is P. In the first phase, the popularity of node is calculated by using the following formula,

$$p = \frac{(n_i + 1)^{\emptyset}}{\sum_j (n_j + 1)^{\emptyset}} \quad (7)$$

Ø is the clustering exponent. After calculating the popularity, some subarea will become the hub as they have a higher probability. In the second step, mobility is induced. A waypoint is selected by choosing subareas along with a position. Nodes select a speed between the maximum and minimum range. But to achieve a steady-state, the minimum speed is also set to nonzero.

C. Interaction among moving agents

In the case of disaster management, there will be different types of moving agents. Now the routing algorithm can be applied to essential route data for relief and rescue operations to reduce the effect of post-disaster situations. The routing algorithm can be effective here. We can use a social-based routing algorithm for detecting interaction among moving agents. It works both with inter-communication and intracommunication. Inter-communications mean communications of nodes among different communities, also known as global communication. Intra-communication means the communication of nodes among the same community, also known as local communication. We suggested a routing technique in an earlier paper. EER [26] mainly uses social-based information to make forwarding decisions. We simulated EER in our customized simulator and compared its performance with other different algorithms. To conduct these experiments, we used SSASY [36], which has 25 participants who were equipped with 802.15.4 Tmote Invent sensors and tracked for 79 days. Some of our experimental result (on the metric of delivery ratio and latency with varying TTL) of our previous work is presented here.

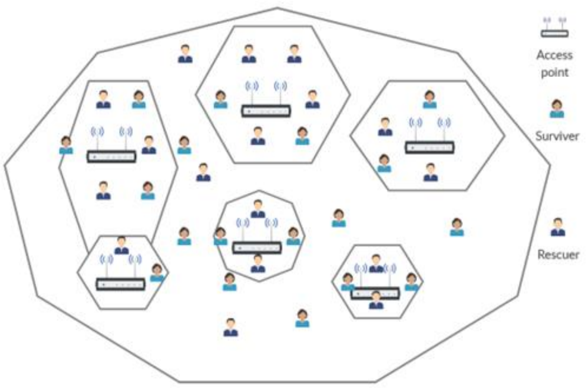

Fig 1: Proposed Model for post disaster communication

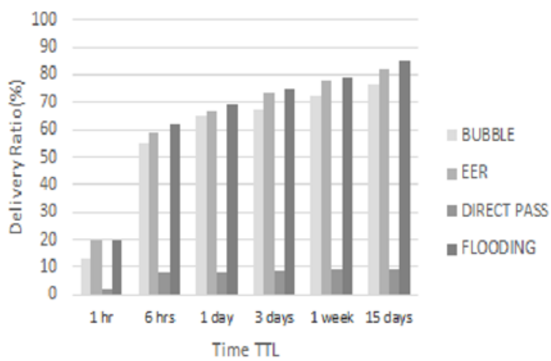

Fig 2: Delivery Ratio with varying TTL

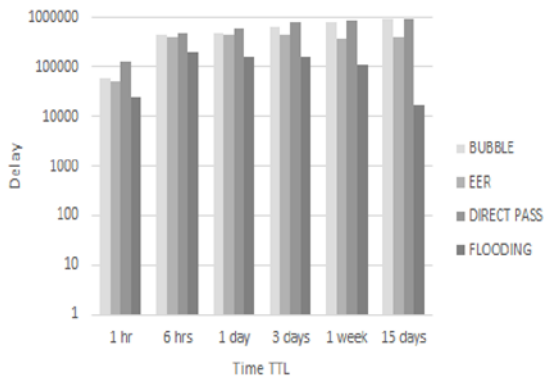

Fig 3: Latency with varying TTL

Our main motive is to minimize the after a disaster situation. A model that can set communications among survivors and rescuers that will help to provide relief and rescue operations. Firstly, we can identify the disaster affected areas, and then we can apply mobility models to define the mobility pattern both for rescuers and survivors. After that, social-based routing algorithms for pocket switched networks can be applied to route all the reliefs to the survivors.

4. Challenges

A. **Clustering the disaster affected area:** As PSN works with the mobile nodes, mobility becomes a prominent characteristic. While clustering, this mobility of nodes should be taken into consideration. But clustering a large network with a mobile node is difficult. Mobility aware clustering can be a solution to this problem. In mobility aware clustering, the cluster architecture is defined by the mobility pattern of nodes [37].

B. **Defining mobility pattern: A**ccording to our proposed model, the total area is divided into different subareas. The members of a subarea are not always fixed as the nodes have their mobility. As a result, defining mobility patterns among these mobile nodes is challenging. As we discussed earlier clustered, mobility model [34] can be a solution.

C. **Interaction among moving agents:** As we are working in such an environment where the communication system is totally broken, so conventional networking concept is not applicable here. Because conventional network needs continuous connectivity. So Psn is an alternative for establishing communication in such a scenario. But it does not provide a high data transmission rate as a conventional network.

This model is not yet implemented. In our subsequent work, we will discuss the experimental result of our proposed model for post-disaster communication.

5. Conclusion

Pocket Switched Networks (PSN) can be implemented without a predefined communication infrastructure. Thus, this networking idea becomes useful in areas where nodes encounter sporadic connections or the communication infrastructure is interrupted, frequently as a result of natural calamities like earthquakes, cyclones, or tsunamis. Following a natural disaster, PSN provides an alternate method for carrying out relief and rescue efforts, which become crucial. The study investigates different PSN routing methods to maximize data transfer and forwarding choices. A further goal of a suggested approach is to create efficient post-disaster communication in order to lessen the effects of the disaster.

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