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Buffer Aware Network Coded Routing Protocol for Delay Tolerant Networks

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Abstract: Delay-Tolerant Networks (DTNs) are a class of networks characterized by intermittent connections and long variable delays. DTNs overcome these problems by store-and-forward method. Routers use buffers to store incoming packets until the forwarding node is identified. In this paper, Buffer Aware Network Coded Routing protocol (BANCRP) for Delay Tolerant Networks is proposed. In this routing protocol, packets are encoded using random linear network coding before transmission; during routing, a node with maximum free buffer space is selected as the forwarding node to avoid buffer overflow and vaccine recovery is implemented by destination for resource saving. Simulation experiments were performed using NS2. The efficiency of protocol is evaluated using parameters such as packet delivery ratio, average delay, buffer utilization and overhead. Simulation results show that BANCRP performs better than other existing DTN routing protocols such as epidemic, Spray and Wait and Spray and Focus.

Key words: Delay Tolerant Network · Routing · Buffer · Network Coding

INTRODUCTION

Networks that employ techniques for producing applications that can tolerate disruptions and high delays in network connectivity are referred as Delay Tolerant Networks (DTNs)[1] or Intermittently Connected Mobile Networks (ICMNs). DTNs overcome the problems associated with intermittent connections, long variable delays, asymmetric data rate and high error rates by using store and forward routing. A node stores a message in its buffer and carries it along for long period of time, until an appropriate forwarding opportunity arises. A reliable transmission can only be attained if a source node keeps a copy of the bundle until it receives an acknowledgement from the receiver and will resend bundle if does not receive acknowledgement. DTNs find application in many areas such as interplanetary networks, vehicular ad hoc networks, under water networks, sensor networks for wildlife tracking, military networks, remote rural village networks and disaster recovery systems. Traditional routing protocols assume that end to end path exists between communication nodes. In DTN as there is no assurance about the existence of path in the network between the source and destination, it is a challenge to construct the best routing protocol.

Routing protocols in DTN can be broadly classified as flooding based routing protocol [1] and forwarding based routing protocol [2,3,4,5] according to the type of information gathered by nodes to take the routing decision. Flooding based routing protocols spread the message and it's replica in the network. They vary according to their spreading mechanism and number of copies forwarded. Forwarding based routing protocols uses different mechanism to efficiently select the relay nodes to enhance the delivery probability in case of limited resources and storage. They gather information about other nodes in the network to select relay nodes.

Epidemic [1] routing was the first flooding based DTN routing protocol. In Epidemic routing, every node sends messages to every node in its communication range and if it does not already have the message copy. This protocol provides high replication and hence this strategy could be applied only in very sparse networks transmitting small size messages. It has very high overhead, high resource consumption and has a large number of message copies in a network which results in network congestion.

Spray and Wait [2] protocol limits the blind forwarding message strategy of Epidemic routing by forwarding maximum of L copies of the message to the

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relay nodes. It consists of two phases spray phase and wait phase. In the spray phase the source node initially spray L number of message copies to L distinct relay nodes. After receiving the message copy all L relay nodes go into the wait phase and wait till the direct transmission to the destination. The spray phase in the Spray and Focus [3] has the same message dissemination scheme as the Spray and Wait routing and in the focus phase it performs single copy utility based transmission among the intermediate relay nodes until the message arrives at the destination. The efficiency of these protocols depends on choosing the optimum 'L' value.

PROPHET [4] calculates delivery probability of the neighbor nodes based on the number of times it had visited a particular location. The higher delivery predictability for a node indicates that it is more reliable than other nodes to forward message to destination. In MaxProp [5] routing each node initially calculates a probability of meeting to all the other nodes in network and also exchanges these values to its neighbor nodes. The probability value is used to calculate a destination path cost. Each node forwards messages through the lowest cost path. MaxProp has poor performance when nodes have small buffer sizes.

Network Coding minimizes the number of transmissions in wireless networks. This allows the intermediate nodes to generate new packets by combining the packets received on their incoming edges. Yun Feng Lin et. al proposed priority coding protocol [6] which uses randomized network coding in epidemic routing. When replication is used to minimize transmission delay, a node should transmit a packet with the minimum number of replicas in the network. When network coding is used, a node can transmit any coded packet, since all of them can equally contribute to the eventual delivery of all data packets to the destination with high probability. Network coding delivers data with shorter delays when resources such as bandwidth and buffer are limited. As each packet is duplicated by the nodes in the network, when it is first delivered to the destination, there are multiple copies of the packet in the network. A recovery scheme called Vaccine [7] is used to delete these obsolete copies from the network to free up through the network to delete buffered copies of this packet.

Due to short comings in existing methods such as (i) not providing a fixed buffer size during simulation that does not depict real scenario (ii) not considering available free space in buffer when selecting a forwarding node (iii) selecting more than one forwarding node, in this paper a new routing protocol called Buffer Aware Network Coded Routing protocol (BANCRP) is proposed. In BANCRP when a message has to be forwarded, packets are encoded using random linear network coding before transmission; during routing, a node in transmission range with maximum free buffer space is selected as the forwarding node to avoid buffer overflow and vaccine recovery is implemented by destination for resource saving.

In the following Sections, the proposed routing algorithm, implementation, results and conclusion are discussed in detail.

Proposed Routing Algorithm: The details of BANCRP are presented in this section

System Model: The DTN model comprises of mobile nodes. Nodes are assumed to have limited buffer size. Every message has a particular time to live and have limited bandwidth. Messages are kept in buffer until destination is met or an intermediate node becomes available

BANCRP: The proposed routing protocol consists of the 3 phases

- Messages are encoded before transmission
- Forwarding node is identified during routing
- Vaccine recovery is implemented during acknowledgement

Message Encoding: Each message on an output link is a copy of a message that arrived earlier on an input link. Random linear network coding allows each node in a network to perform computation. Therefore, in network coding, each message sent on a node's output link is a function or "mixture" of messages that arrived earlier on the node's input links. Thus, network coding is generally the transmission, mixing (or encoding) and re-mixing (or re-encoding) of messages arriving at nodes inside the network, such that the transmitted messages can be unmixed (or decoded) at their final destinations. When two streams of information, both at bitrate ?? bits per second, arrive at a node, contending for an output link, having capacity ?? bits per second, with network coding, the throughput is increased by pushing both streams through the link at the same time. Using network coding, the node can mix the two streams together by taking their exclusive-OR (XOR) bit-by-bit and sending the mixed stream through the link. In this case, XOR is the function computed at the node. This increases the throughput of the network if the two streams can be decoded when they reach their final destinations.

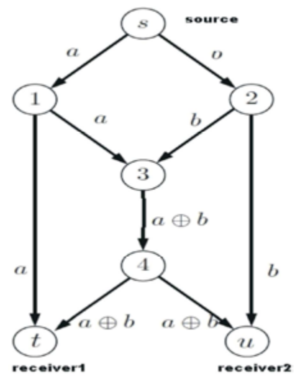

Fig. 1: Network Coding

Forwarding Node Identification: The source node can be modeled as an M/M/1/q* queue.

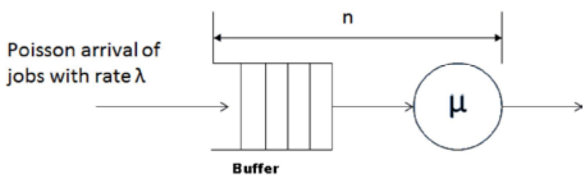

Fig. 2: M/M/1/q* Queue

By the large deviation principle on queues [8], under stable condition ($\lambda < \mu$), the probability that the queue size is greater than some large value (P[Q > q*]) decays exponentially as follows:

$$\lim_{l\to\infty}\frac{1}{l}\ln P\left(\frac{Q}{l}>q^*\right)=-q^*\times\sup\left\{\theta:\wedge_{5(-\theta)}\le 0\right\}$$

Where [$\wedge_{A(\theta)}+\wedge_{5(-\theta)}$] is the cumulative (log moment) generating function of the queue process expressed in terms of the respective exponential arrival and service processes. Fixing the overflow probability to a value close to 0 and computing the slope in above Equation would yield the buffer size q*.

In case of M/M/1 queue model:

- Arrivals occur at rate λ according to a Poisson process and move the process from state i to i + 1.
- Service times have an exponential distribution with parameter $1/\mu$ in the M/M/1 queue, where μ is the mean service rate.

Delay Tolerant Networks are opportunistic networks composed of mobile nodes that do not always have a direct connection between them. As routes are built dynamically, each node works according to the store and forward paradigm. Nodes store data they generate or receive, carry it around until they find a suitable carrier (or the destination) and then forward it. Thus, contacts between nodes are viewed as an opportunity to move data closer to the destination.

Each node transmits HELLO packets with source address and sequence number and count of their buffered message, every second to all the nodes in its communication range. Nodes, on receiving the packet update their routing table. When the messages are encoded and are to be transmitted by a node, the forwarding node has to be identified. From the routing table, node with minimum count of messages is identified as the forwarding node.

Vaccine Recovery: Anti-packet is generated by the destination when it first receives a packet, which is then propagated in the entire network, in the same fashion that a data packet is propagated under epidemic routing, to delete obsolete copies of the packet.

```
while contacton(i,j)
        send HELLOpacket(i,j)
        update routing table
        send msg
        perform RLNC
        identify forwarding node
        send ACK
end while
function send HELLO packet(i,j)
        for each second
            send HELLO packet(m id, seq no., free
            buffer space)
        end for
function update routing table
        for every HELLO packet
            Routing table updated
        end for
function sendmsg(i,j)
        for each msg generated
            RLNC is performed
        end for
end function sendmsg
function identify forwarding node
        for each transmission
            node with max free space identified
        end for
```

end function identifyforwarding node
function sendACK
for each recvd packet
ACK is sent
end for
end function sendACK
function RLNC(a,b)
c = a xOR b
end function RLNC

Pseudocode for BANCRP

RESULTS

The proposed routing protocol BANCRP and the protocols in comparison, epidemic, spray and wait, spray and focus, ENCP are evaluated using NS 2 simulation.

Performance Metrics: The performance metrics used for evaluation are:

- Delivery ratio, which is defined as the ratio of number of messages successfully delivered to destination to the total number of messages generated
- Delivery latency, which is defined as the average delay needed to deliver a message to the destination.
- Overhead ratio, which is defined as the ratio of total number of relayed messages to the total number of messages delivered
- Buffer Unutilized, defined as the max free buffer space during transmission

The delivery ratio, delivery latency show the success of routing algorithm in delivering messages while overhead ratio and buffer space depicts the judicious usage of network resources.

The following table summarizes the simulation parameters used

No. of nodes	50, 100, 150 and 200 nodes
Area Size	6000 m x 6000 m
MAC	802.11
Simulation Time	5000 s
Traffic Source	CBR
Packet Size	500 bytes
Transmission range	250 m
Mobility Model	Random Way Point Model
Routing Protocol	BANCRP
Rate	50 kbps
Speed	5, 10, 15 and 20 m/s

Figure 1 shows the mobility of 150 nodes in ns 2 simulator

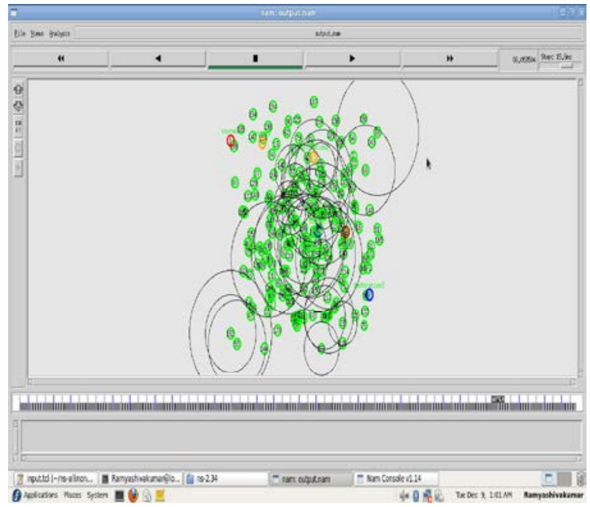

Fig. 3: Mobility of 150 nodes

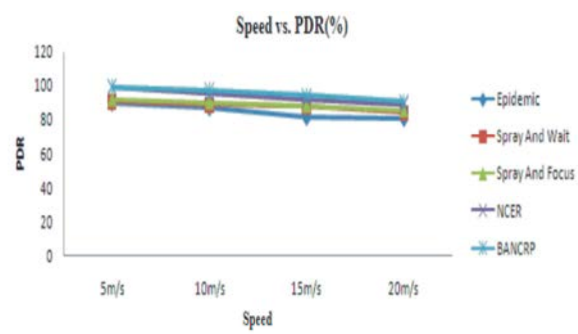

Fig. 4: Speed vs. Packet delivery ratio(%)

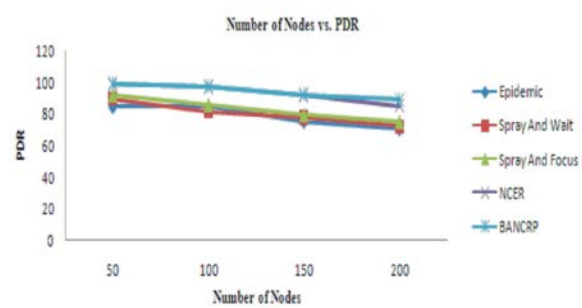

Fig. 5: Number of nodes vs. PDR(%)

It is observable from figure 4 and figure 5 that the packet delivery ratio (PDR), where BANCRP achieves higher PDR when compared with epidemic, spray and wait, spray and focus routing protocols by 16% with respect to speed and 20% with respect to the number of nodes since the packet size is compressed and is as shown below where the x-axis is speed, number of nodes and the y-axis is packet delivery ratio.

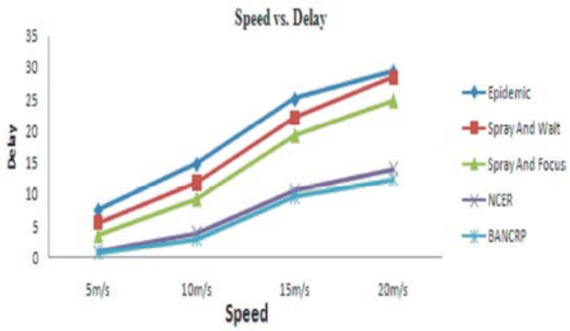

Fig. 6: Speed vs. Average Delay

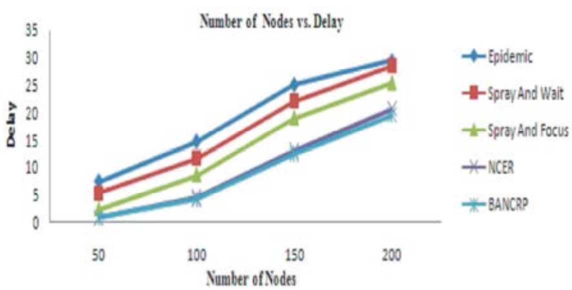

Fig. 7: Number of nodes vs Delay

Fig. 8: Speed vs. Buffer Unutilized

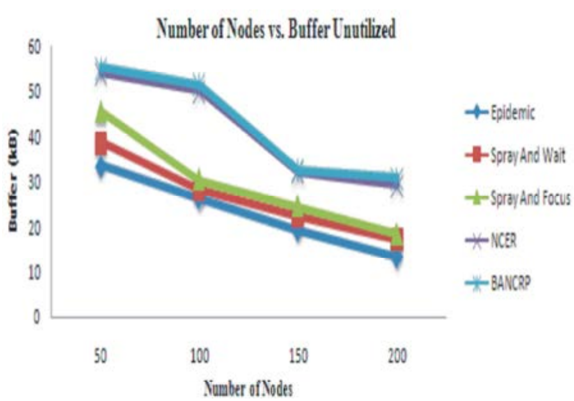

Fig. 9: Number of nodes vs. Buffer unutilized

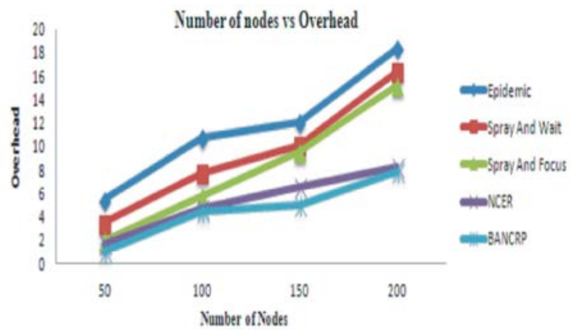

Fig. 10: Number of nodes vs. Overhead

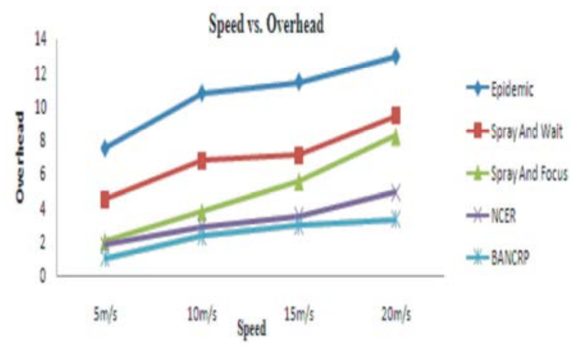

Fig. 11: Speed vs. Overhead

Figure 6 and figure 7 depicts the average delay, where BANCRP achieves lesser delay when compared with epidemic, spray and wait, spray and focus routing protocols by 15% with respect to speed and 10% with respect to the number of nodes since BANCRP transmits a batch of data packets and is as shown below where the x-axis is speed, number of nodes and the y-axis is average delay.

It is apparent from the figure 8 and figure 9 that the BANCRP achieves better performance compared with that of the other protocols since network coding compresses the packet size and the BANCRP utilizes buffer 20% higher than that of the other protocols with respect to speed and 25% extra with respect to number of nodes and is as shown below where the x-axis denotes speed, number of nodes and the y-axis denotes buffer utilization

It is obvious from the figure 10 and figure 11 that the overhead of BANCRP is lesser and BANCRP attains lesser by 9% than that of the other protocols with respect to speed and 6% with respect to nodes compared with the other protocols since buffer utilization of BANCRP is higher and is as shown below where the x-axis is number of nodes, speed and the y-axis is overhead.

CONCLUSION

In this paper, we proposed a routing protocol called BANCRP (Buffer Aware Network Coded Routing Protocol) that encodes messages before transmission, identifies forwarding node with maximum free buffer space and sends acknowledgement on reception to clear the obsolete copies. The protocol was implemented using ns 2. It was found to have increased packet delivery ratio, decreased delay, lesser overhead and efficient utilization of buffer when compared with other protocols such as epidemic, spray and wait, spray and focus and NCER. As future work, usage of energy and bandwidth, the other two important resources of DTNs can also be analyzed in this protocol.

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