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QoS Improvement in MANET Using Crosslayer Back Pressure Routing with Adaptive Redundancy

by

Ashutosh Ghimire

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A thesis submitted in partial fulfilment of the requirements

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Abstract

A MANET is an autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links. MANET are both self-forming and self-healing, enabling peer-level communications between mobile nodes without reliance on centralized resources or fixed infrastructure. Although, many routing protocols have been developed for MANET, widespread use of MANET have not been seen outside of experimental labs and simulation environment. Energy efficiency and delay performance of existing routing protocols are not good enough as they do not consider energy as a parameter and thus need to be optimized. In this research two existing concepts; adding Adaptive Redundancy and Crosslayer routing to improve delay and energy efficiency respectively are merged to form a new routing model. Furthermore, the proposed model of Crosslayer Back Pressure Routing with Adaptive Redundancy has been tested and compared with existing routing protocols using NS-3 and found to have the best delay and energy performance.

Keywords: MANET, NS-3, Ad-hock, Back Pressure, Crosslayer

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List of Abbreviation

AODV	Ad-Hoc On Demand Distance vector routing
CRC	Cyclic Redundancy Check
DSDV	Destination sequenced distance vector routing
DSR	Dynamic Source Routing
DTN	Delay Tolerant Networks
FIFO	First In First Out
GNU	GNU’s not UNIX
GPLV2	General Public License Version 2
GW	Gateways
ISM Band	Industrial Scientific and Medical radio Band
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network
MAP	Mesh Access Points
MC	Mesh Controller
NS-3	Network Simulator 3
OLSR	Optimized Link State Routing
QoS	Quality of Service
RSS	Receive Signal Strength
TCP/IP	Transmission Control Protocol / Internet Protocol
TDMA	Time Division Multiple Access
WLAN	Wireless Local Area Network
UNII Band	Unlicensed National Information Infrastructure radio Band

Chapter 1 Introduction

1 INTRODUCTION

1.1 Background

One of the emerging trends in today's commercial communication market is the adoption of wireless technology. In the next generation of wireless communication systems, there will be a great demand for the rapid deployment of independent mobile users and these network scenarios cannot depend on centralized and organized connectivity. [1]

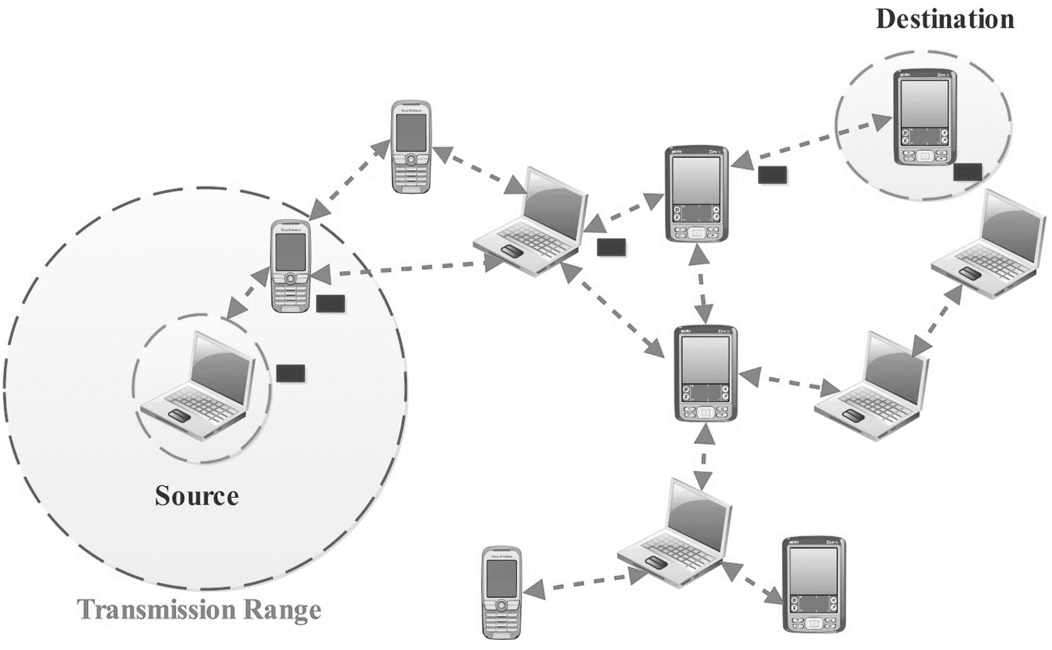

Figure 1-1 MANET Architecture

A mobile ad hoc network (MANET) is a continuously self-configuring, infrastructure-less network of mobile devices connected without wires. Each device in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. Each must forward traffic unrelated to its own use, and therefore be a router. The primary challenge in building a MANET is equipping each device to continuously maintain the information required to properly route traffic. Such networks may operate by themselves or may be connected to the larger Internet. They may contain one or multiple and different transceivers between nodes. This results in a highly dynamic, autonomous topology. [2]

The set of applications for MANETs is diverse, ranging from small, static networks that are constrained by power sources, to large-scale, mobile, highly dynamic networks. The design of network protocols for these networks is a complex issue. Regardless of the application, MANETs need efficient distributed algorithms to determine network organization, link scheduling, and routing. However, determining viable routing paths and delivering messages in a decentralized environment where network topology fluctuates is not a well-defined problem. While the shortest path (based on a given cost function) from a source to a destination in a static network is usually the optimal route, this idea is not easily extended to MANETs. Factors such as variable wireless link quality, propagation path loss, fading, multiuser interference, power expended, and topological changes, become relevant issues. The network should be able to adaptively alter the routing paths to alleviate any of these effects. Moreover, in a military environment, preservation of security, latency, reliability, intentional jamming, and recovery from failure are significant concerns. Military networks are designed to maintain a low probability of intercept and/or a low probability of detection. Hence, nodes prefer to radiate as little power as necessary and transmit as infrequently as possible, thus decreasing the probability of detection or interception. A lapse in any of these requirements may degrade the performance and dependability of the network.

In such applications mobile ad hoc networks (MANETs) play an important role. Ad hoc wireless networks are highly appealing for many reasons. They have the advantage of rapid deployment and reconfiguration. It is easy to adapt the network to specific applications. They are highly robust due to their distributed nature, and the lack of single point of failure. While ad hoc networks exhibit much promise, they also pose some significant design challenges. The challenges are due to their lack of established infrastructure, dynamic topology, wireless channel characteristics and their decentralized nature.

1.2 Related Theories

1.2.1 Routing

Routing is the process of selecting best paths in a network. In the past, term routing also meant forwarding network traffic among networks. However, that latter function is better described as forwarding. Routing is performed for many kinds of networks, including the telephone network (circuit switching), electronic data networks (such as the Internet), and transportation networks.

In packet switching networks, routing directs packet forwarding (the transit of logically addressed network packets from their source towards their ultimate destination) through intermediate nodes. Intermediate nodes are typically network hardware devices such as routers, bridges, gateways, firewalls, or switches. General-purpose computers can also forward packets and perform routing, though they are not specialized hardware and may suffer from limited performance. The routing process usually directs forwarding on the basis of routing tables, which maintain a record of the routes to various network destinations. Thus, constructing routing tables, which are held in the router's memory, is very important for efficient routing. Most routing algorithms use only one network path at a time. Multipath routing techniques enable the use of multiple alternative paths.

1.2.2 Wifi 802.11 family

The 802.11 family consists of a series of half-duplex over-the-air modulation techniques that use the same basic protocol. 802.11-1997 was the first wireless networking standard in the family, but 802.11b was the first widely accepted one, followed by 802.11a, 802.11g, 802.11n, and 802.11ac. Other standards in the family (c–f, h, j) are service amendments that are used to extend the current scope of the existing standard, which may also include corrections to a previous specification

802.11b and 802.11g use the 2.4 GHz ISM band. Because of this choice of frequency band, 802.11b and 802.11g equipment may occasionally suffer interference from microwave ovens, cordless telephones, and Bluetooth devices. 802.11b and 802.11g control their interference and susceptibility to interference by using direct-sequence spread spectrum (DSSS) and orthogonal frequency-division multiplexing (OFDM) signaling methods, respectively. 802.11a uses the 5 GHz U-NII band, which, for much of the world, offers at least 23 non-overlapping channels rather than the 2.4 GHz ISM frequency band offering only three non-overlapping channels, where other adjacent channels overlap[3]. Better or worse performance with higher or lower frequencies (channels) may be realized, depending on the environment.

IEEE 802.11 are extensively used for MANET Networks and routing protocols.

1.2.3 MANET Routing

An ad hoc routing protocol is a convention, or standard, that controls how nodes decide which way to route packets between computing devices in a mobile ad hoc network. In ad hoc networks, nodes are not familiar with the topology of their networks. Instead, they have to discover it: typically, a new node announces its presence and listens for announcements broadcast by its neighbors. Each node learns about others nearby and how to reach them, and may announce that it too can reach them.

There are two types of ad hoc network routing protocols.

Table-driven (proactive) routing

This type of protocol maintains fresh lists of destinations and their routes by periodically distributing routing tables throughout the network[4]. The main disadvantages of such algorithms are:

i) Respective amount of data for maintenance.
ii) Slow reaction on restructuring and failures.

Examples of such routing are Optimized Link State Routing protocol (OLSR) and Destination Sequenced Distance Vector (DSDV)

On-demand (reactive) routing

This type of protocol finds a route on demand by flooding the network with Route Request packets.[4] The main disadvantages of such algorithms are:

i) High latency time in route finding.
ii) Excessive flooding can lead to network clogging.

Examples of on-demand algorithms are: Ad-Hoc On Demand distance vector (AODV) and Dynamic Source Routing (DSR)

1.2.4 Back Pressure Routing

In queuing theory, a discipline within the mathematical theory of probability, the Back Pressure routing algorithm is a method for directing traffic around a queueing network that achieves maximum network throughput which is established using concepts of Lyapunov drift. [5] Back Pressure routing considers the situation where each job can visit multiple service nodes in the network. It is an extension of max-weight scheduling where rather each job visits only a single service node. Back Pressure routing is an algorithm for dynamically routing traffic over a multi-hop network by using congestion gradients. The algorithm can be applied to wireless communication networks, including sensor networks, mobile ad hoc networks (MANETS), and heterogeneous networks with wireless and wireline components.

The Back Pressure algorithm can be applied even in multi-commodity networks (where different packets may have different destinations), and to networks where transmission rates can be selected from a set of (possibly time-varying) options. The main advantages of using the Back Pressure routing algorithm are:

(i) it has maximum network throughput,

(ii)it is robust to time-varying network conditions,

(iii)it can be implemented without knowing traffic arrival rates or channel state probabilities.

1.2.5 AODV Routing

AODV is a method of routing messages between mobile computers. It allows these mobile computers, or nodes, to pass messages through their neighbors to nodes with which they cannot directly communicate. AODV does this by discovering the routes along which messages can be passed. AODV makes sure these routes do not contain loops and tries to find the shortest route possible. AODV is also able to handle changes in routes and can create new routes if there is an error.

Nodes you can communicate with directly are considered to be Neighbors. A node keeps track of its Neighbors by listening for a HELLO message that each node broadcast at set intervals. When one node needs to send a message to another node that is not its Neighbor it broadcasts a Route Request (RREQ) message. The RREQ message contains several key bits of information: the source, the destination, the lifespan of the message and a Sequence Number which serves as a unique ID.[4]

1.2.6 DSDV Routing

The DSDV (destination-sequenced distance vector) protocol uses the Bellman-Ford algorithm to calculate paths. The cost metric used is the hop count, which is the number of hops it takes for the packet to reach its destination. DSDV is a table driven proactive protocol, thus it maintains a routing table with entries for all the nodes in the network and not the neighbors of a node. The changes are propagated through periodic and trigger update mechanisms used by DSDV Due to these updates there is a chance of having routing loops in the network. To eliminate routing loops, each update from the node is tagged with a sequence number.[4]

Mobility of the nodes in MANETs causes route fluctuations for which DSDV uses settling time to dampen.

1.2.7 DSR Routing

The Dynamic Source Routing protocol (DSR) is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of the two mechanisms of Route Discovery and Route Maintenance, which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the ad hoc network. [4]The use of source routing allows packet routing to be trivially loop-free, avoids the need for up-to-date routing information in the intermediate nodes through which packets are forwarded, and allows nodes forwarding or overhearing packets to cache the routing information in them for their own future use.

All aspects of the protocol operate entirely on-demand, allowing the routing packet overhead of DSR to scale automatically to only that needed to react to changes in the routes currently in use.

1.2.8 Network Simulator

In communication and computer network research, network simulation is a technique where a program models the behavior of a network either by calculating the interaction between the different network entities (hosts/packets, etc.) using mathematical formulas, or actually capturing and playing back observations from a production network. The behavior of the network and the various applications and services it supports can then be observed in a test lab; various attributes of the environment can also be modified in a controlled manner to assess how the network would behave under different conditions.

NS-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use. NS-3 is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use.

Netanim animator was used to visualize the protocol performance compared to other protocols and various number of nodes.

1.2.9 Transmission delay

In a network based on packet switching, transmission delay (or store-and-forward delay, also known as packetization delay) is the amount of time required to push all the packet's bits into the wire. In other words, this is the delay caused by the data-rate of the link.Transmission delay is a function of the packet's length and has nothing to do with the distance between the two nodes. This delay is proportional to the packet's length in bits[5],It is given by the following formula:

$D_T = N/R$ seconds………………………………………………………(1)

Where D_T is the transmission delay in seconds,

N is the number of bits and

R is the rate of transmission (in bits per second)

Most packet switched networks use store-and-forward transmission at the input of the link. A switch using store-and-forward transmission will receive (save) the entire packet to the buffer and check it for CRC errors or other problems before sending the first bit of the packet into the outbound link. Thus, store-and-forward packet switches introduce a store-and-forward delay at the input to each link along the packet's route.

1.2.10 Energy Consumption

Energy consumption is a key issue in network devices specially in wireless devices as the devices are usually battery powered. We know the factors that cause the energy consumption in devices are the routing protocols that are used in routing packets from one node to another. By precise monitoring of the functions of the network devices and the flow of packets energy consumption of network devices can be calculated [6]. The energy consumption by the devices mainly depend on the following factors.

i) Technology: The access technology makes the huge difference in power consumption by the network. Wireless technology uses the most energy due to significant loss while transmitting power through air interface. Wireline Technology consumes the least energy as compared to wireless but is significantly higher compared to Optical fiber technology which has the lease attenuation.

ii) Size of data: The amount of data that has to be transmitted also plays important part in energy consumption. The more the data is to be transmitted more energy is consumed.
iii) Size of Network: The size of network is also another factor. Usually the amount of energy consumption increases with the size of network.

1.3 Problem Definition

A mobile ad hoc network consists of several nodes that forward the information from one node to the other nodes. Many conventional routing protocols like AODV, DSDV, DSR etc. were proposed to route the information. But the problem with these routing protocols is that, they do not consider energy as a metric or a parameter. Since these nodes are battery powered, when we are using one node continuously the energy of the nodes get exhausted. So, to account for this issue, various energy efficient routing protocols have also been proposed.

Quality of Service of a network is mainly governed by three parameters delay, latency and jitter. Specially in case of mobile ad-hoc network energy is also another important constraint. Thus in this research, a novel routing algorithm obtained by combining two existing techniques of adding Adaptive Redundancy and Crosslayer approach to backpressure routing to get a delay and energy consumption optimized routing is proposed.

1.4 Objective

i) Enhance Back Pressure Routing by introducing Adaptive Redundancy of packets to improve delay performance.

ii) Increase energy efficiency of Routing by using cross layered approach in network layer and Mac Layer

1.5 Scope and Application

Various MANET related platforms are being developed day to day. The routing model proposed can be used in any such platforms such as VANETs or WSNs.This routing model is especially important to WSNs as they need very high energy efficiency.

Chapter 2- Literature review

2 LITERATURE REVIEW

2.1 Back Pressure Routing algorithm

The Back Pressure routing algorithm is a centralized method for directing traffic around a queuing network that achieves maximum network throughput. Back Pressure routing is an algorithm for dynamically routing traffic over a multi-hop network by using congestion gradients. The algorithm can be applied to wireless communication networks, including sensor networks, mobile ad hoc networks (MANETS), and heterogeneous networks with wireless and wire line components. Back Pressure principles can also be applied to other areas, such as to the study of product assembly systems and processing networks. It is mainly focused on communication networks, where packets from multiple data streams arrive and must be delivered to appropriate destinations. The Back Pressure algorithm operates in slotted time. Every time slot it seeks to route data in directions that maximize the differential backlog between neighboring nodes [7]. This is similar to how water flows through a network of pipes via pressure gradients.

In essence, Back Pressure assumes a globally synchronized time-slotted MAC protocol as well as a central controller that computes and disseminates a schedule (i.e., a set of links allowed to transmit) for each time slot. Moreover, the schedule computation requires the global knowledge of per-flow queue backlogs and network state (i.e., link quality and link interference pattern), which therefore must be measured at the wireless nodes and provided to controller in a timely manner. Practical Back Pressure systems that relax some of these assumptions and approximate the Back Pressure algorithm on top of the 802.11 MAC protocol have been proposed. Even though these approaches have shown performance benefits, the step towards a practical system implementing optimal Back Pressure scheduling has not yet been made.

2.1.1 Traditional Back Pressure Scheduling and Routing

For each node that maintains N − 1 queues, one for each commodity, with the j^{th} queue at each node containing packets that are destined for node j. Let $Q_i^c(t)$ indicate the number of packets destined to node c queued at node i at time t. Naturally, $Q_i^i(t) = 0 \ \forall_t$. Let $\mu_{ij}^c(t)$ be the scheduling and routing variable that indicates the number of packets of commodity c to be scheduled on link (i, j). Back Pressure scheduling/routing selects the $\mu_{ij}^{c}(t)$ that solve the following problem (a form of maximum weight independent set selection):

$$\max \sum_{(i,j,c)} \Delta_{ij}^{c}(t).\, \mu_{ij}^{c}(t)$$

subject to,

$$\sum\nolimits_{c} \mu_{ij}^{c}(t) \leq \theta_{ij}(t), \qquad \forall_{i,} \forall_{j}$$

$$\mu_{ij}^{c}(t).\, \mu_{km}^{d}(t) = 0, \big((i,j),(k,m)\big) \,\epsilon\, \Omega(t), \forall_{c}, \forall_{d}$$

$\mu_{ij}^{c}(t) \geq 0, \forall_{i}\forall_{j}\forall_{c}$……………………………………………………………(1)

Where $\Delta_{ij}^{c}(t) = Q_{i}^{c}(t) - Q_{j}^{c}(t)$ is the link weight, which denotes the queue differential for commodity c on link (i, j) at slot t. $\theta_{ij}(t)$ is the channel state in terms of number of packets that can be transmitted over link (i, j) during slot t. Ω(t) is the link interference set at slot t such that if link (i, j) interferes with link (i′, j′) at slot t then ((i, j), (i′, j′)) ∈ Ω(t) and hence, those two links cannot be both scheduled at slot t. The maximization problem in (1) can be solved by finding the maximum commodity $c_{ij}^{*}(t)$ for each link (i, j) at slot t that maximizes $\Delta_{ij}^{c}(t)$ and assign $\mu_{ij}^{c}(t) = 0$ for all $c \neq c_{ij}^{*}(t)$
and then solve,

$$\max \sum_{(i,j,c)} \Delta_{ij}^{c_{ij}^{*}(t)}(t).\, \mu_{ij}^{c_{ij}^{*}(t)}(t)$$

subject to,

$$\sum\nolimits_{c} \mu_{ij}^{c_{ij}^{*}(t)}(t) \leq \theta_{ij}(t), \qquad \forall_{i,} \forall_{j}$$

$$\mu_{ij}^{c_{ij}^{*}(t)}(t).\, \mu_{km}^{c_{km}^{*}(t)}(t) = 0, \big((i,j),(k,m)\big) \,\epsilon\, \Omega(t), \forall_{c}, \forall_{d}$$

$\mu_{ij}^{c_{ij}^{*}(t)}(t)\ 0, \forall_{i}\forall_{j}\forall_{c}$……………………………………………………………(2)

2.1.2 Back Pressure Routing with Adaptive Redundancy

Enhancement of Back Pressure with adaptive redundancy can be done as follows. An additional set of N−1 duplicate buffers of size D_{max} is created at each node. Besides the original queue occupancy $Q^{c}_{i}(t)$ which has the same meaning as in traditional Back Pressure, the duplicate queue occupancy is denoted by $D^{c}_{i}(t)$, that indicates the number of duplicate packets at node i that are destined to node c at time t. Again, Q_i i(t) = D_i i(t) = 0 ∀t since destinations need not buffer any packets intended for themselves. The duplicate queues are maintained and utilized as follows: Original packets when transmitted are removed from the main queue; however, if the queue size is lower than a certain threshold q_{th}, then the transmitted packet is duplicated and kept in the duplicate buffer associated with its destination if it is not full (otherwise no duplicate is created). Setting both q_{th} and D_{max} to the value of the maximum link service rate is enough and gives superior delay results. Duplicate packets are not removed from the duplicate buffer when transmitted. They are only removed when they are notified to be received by the destination, or a pre-defined timeout has occurred. When a certain link is scheduled for transmission, the original packets in the main queue are transmitted first. If no more original packets are left, only then duplicates are transmitted. Thus the duplicate queue has a strictly lower priority. Ideally, all copies of a delivered packet in the network should be deleted instantaneously when the first copy is delivered to the intended destination. Similar to original Back Pressure scheduling/routing, the BWAR scheduling/routing also requires the solution of a similar maximum weight independent set problem.

$$\max \sum_{(i,j,c)} \Delta^{c}_{BWAR,ij}(t).\,\mu^{c}_{ij}(t)$$

subject to,

$$\sum_{c} \mu^{c}_{ij}(t) \le \theta_{ij}(t), \qquad \forall_{i,}\forall_{j}$$

$$\mu^{c}_{ij}(t).\,\mu^{d}_{km}(t) = 0, \big((i,j),(k,m)\big) \in \Omega(t), \forall_{c}, \forall_{d}$$

$$\mu^{c}_{ij}(t) \ge 0, \forall_{i}\forall_{j}\forall_{c} \qquad (3)$$

An enhanced link weight for BWAR, $\Delta^{c}_{BWAR,ij}(t)$ is defined as follows, to take into account the occupancy of the duplicate buffer.

$$\Delta^{c}_{BWAR,ij}(t) = Q^{c}_{i}(t) - Q^{c}_{j}(t) + \frac{1}{2}\left(1_{j=c \text{ and } Q^{c}_{i}(t)+D^{c}_{i}(t)>0}\right) + \frac{1}{4}\frac{1}{D_{max}}\left(D^{c}_{i}(t) - D^{c}_{j}(t)\right) \qquad (4)$$

Here the indicator function $1_{j=c \text{ and } Q^{c}_{i}(t)+D^{c}_{i}(t)>0}$ denotes that node j is the final destination for the considered commodity c. This gives higher weight to commodities that encounter their destinations. This effectively results in dramatic delay improvement. Similarly, the maximization problem in (3) can be solved first by finding the maximum commodity $c^*_{BWAR,ij}(t)$ for each link (i,j) at slot t that maximizes $\Delta^c_{BWAR,ij}(t)$ followed by the same approach discussed earlier.

2.2 Cross-layer optimization

Cross-layer optimization is an escape from the pure waterfall-like concept of the OSI communications model with virtually strict boundaries between layers. The cross layer approach transports feedback dynamically via the layer boundaries to enable the compensation for e.g. overload, latency or other mismatch of requirements and resources by any control input to another layer but that layer directly affected by the detected deficiency.

Existing networks are designed in layers, where protocols operate independently at each layer of the network stack. This approach provides flexibility with a modular design and standardization, but it may result in severe performance degradation when these protocols do not cooperate well. This is usually the case of wireless multi-hop networks, where noise and interference at lower layers affect the routing and congestion control performed at upper layers.[8]

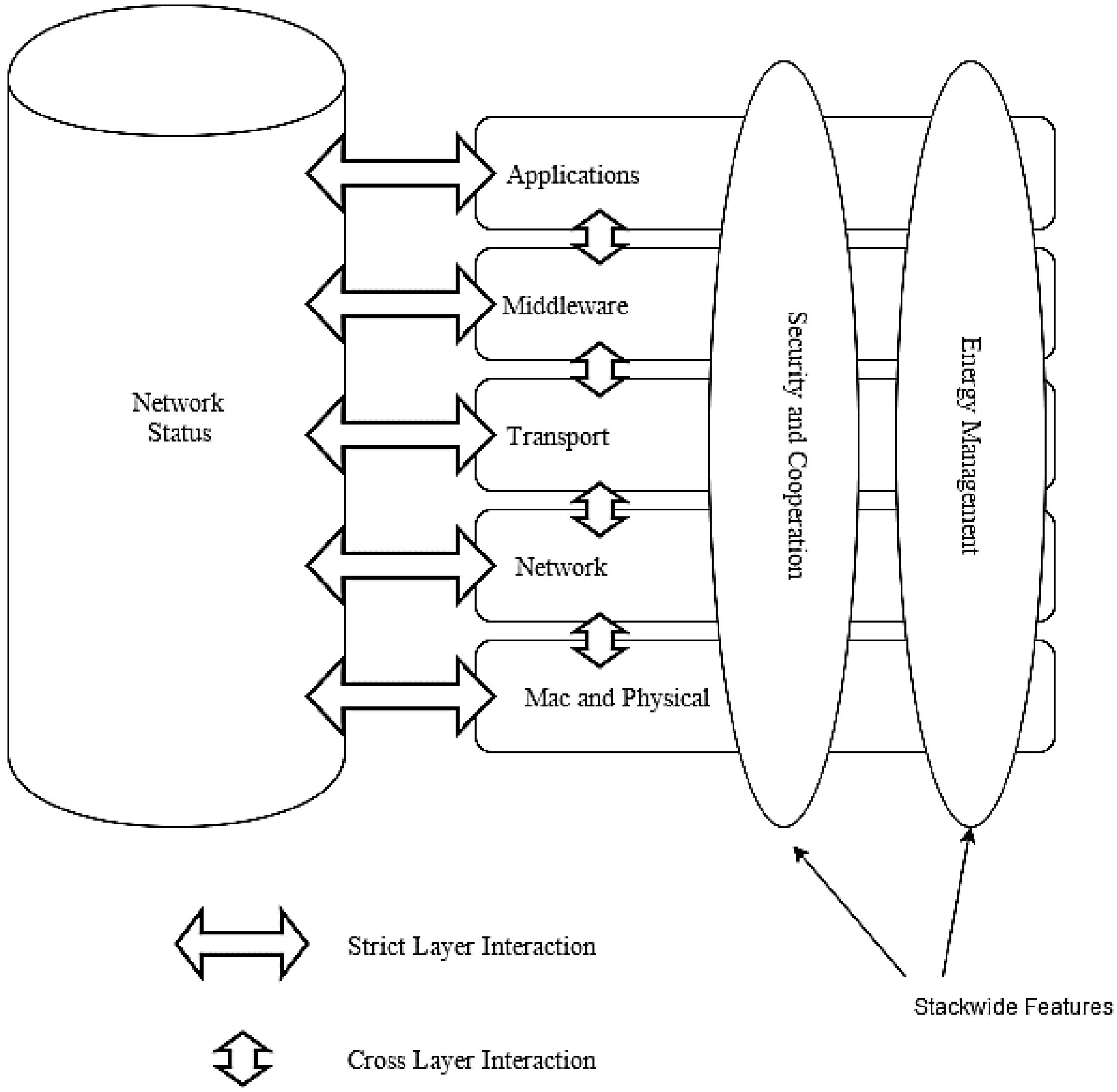

Figure 2-1 Network Architecture of Cross Layer

A common approach to address these performance issues is then to modify a single layer of the protocol stack, while keeping other layers intact. Cross-layer architectures offer a radical alternative by advocating cooperation among the multiple layers of the protocol stack. At the core of these architectures is the Back Pressure scheduling algorithm, which, in theory, achieves the network capacity. Translating this theoretical concept into a practical system, however, entails several challenges, mainly due to its idealized assumptions.

2.2.1 XPRESS Architecture

In XPRESS the wireless network is composed of several mesh access points (MAPs), a few gateways (GWs), and a mesh controller (MC), as depicted in Figure 2-1. The term "node" refers to a mesh node that can be either a MAP or a GW. The MAPs provide wireless connectivity to mobile clients and also operate as wireless routers, interconnecting with each other in a multi-hop fashion to forward user traffic. Mobile clients communicate with MAPs over a different channel, and thus are not required to run the XPRESS protocol stack. [9] The GWs are connected to both the wireless network and the wired infrastructure, and provide a bridge between the two. The MC is responsible for the coordination of the wireless transmissions in the network, and it is analogous to a switching control module. In this design, the MC is deployed in a dedicated node in the wired infrastructure and connects to the gateways through high-speed links. In an alternative design, the MC could be implemented within one of the gateways, when necessary.

The operation of XPRESS is described as follows. XPRESS runs a slotted MAC protocol, where a sequence of slots is organized into frames. For each slot, XPRESS selects a set of non-interfering links to transmit based on the flow queue lengths and the network state. Each node thus maintains per-flow queues, and monitors adjacent links to estimate interference and losses. The queue lengths and network monitoring results are periodically transmitted to the MC over an uplink control channel. Upon reception of this information, the MC updates its local topology and interference databases, and runs the Back Pressure scheduler to calculate the throughput-optimal schedule for multiple upcoming slots (i.e., a frame). The MC then disseminates the resulting schedule to the nodes over a downlink control channel. The nodes in turn apply the new schedule for transmissions in the next frame. This cycle repeats periodically.

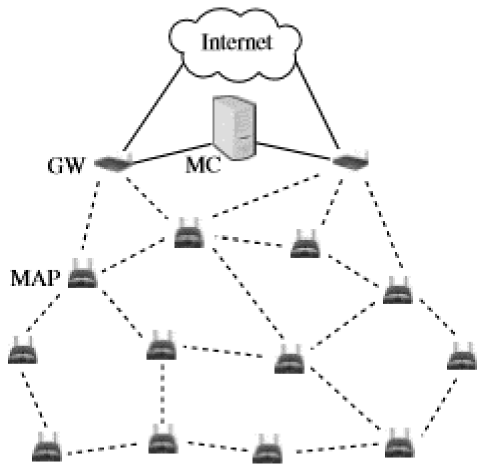

Figure 2-2 Xpress

In XPRESS, ad–hoc network is transformed into a wireless switch, where packet routing and scheduling decisions are made by a Back Pressure scheduler. XPRESS is composed of a central controller, which performs Back Pressure scheduling based on the measured wireless network state, and also of the wireless nodes, which periodically provide the network measurements and execute the computed schedule using a cross-layer protocol stack. The implementation of XPRESS on 802.11 platform is a novel technique that overcomes the above-mentioned Back Pressure challenges and has a wider applicability to the design of centralized multihop wireless systems. The main modifications are as follows. First, as the XPRESS cross-layer stack gracefully integrates the transport, network, and MAC layers. In order to achieve synergy among these layers on programmable 802.11 platform, following steps are implemented (a) a congestion control scheme to ensure the scheduler operates within the capacity region; (b) a coordination mechanism between network-layer flow queues and MAC-layer link queues, which enables per link queue implementation on memory-constrained wireless interfaces; and (c) a multi-hop TDMA MAC protocol that not only ensures global synchronization among nodes, but also enables coordinated transmissions within slot boundaries according to the exact Back Pressure schedule. Second, implementing TDMA MAC on top of 802.11 PHY results in binary interference patterns. This relaxes the channel state estimation requirement from exact values to binary state (i.e., delivery ratios are close to 0% or 100%), which allows to efficiently find the link transmission sets and accurately estimate the queue backlogs of the network. Complementary techniques, such as multi-slot schedule computations and speculative scheduling, reduce the protocol overhead further and provide the scheduler at the controller with a longer computation time budget at the expense of outdated, but still accurate, network state. Third, an interference estimation mechanism with only O(N) measurement complexity that allows the Back Pressure scheduler to determine at the TDMA frame time scale the links which can transmit without interference was tested. The mechanism uses received signal strength (RSS) as well as an adaptive technique based on packet loss to cope with the RSS measurement limitations of 802.11. Fourth, the evaluations in an indoor testbed show that XPRESS provides close to perfect fairness in small-scale centralized WLANs and 63%–128% throughput gains over 802.11 in multi-hop mesh configurations. XPRESS accurately emulates the optimal Back Pressure schedule and delivers relatively low delays when operating close to capacity. Finally,an analysis of the communication and computation overhead of XPRESS and identify different system design choices and limitations was provided.

2.2.2 Data Plane

The XPRESS data plane spans across the transport, network, and MAC layers of the protocol stack, as depicted in Figure 2-3. The transport and network layers implement congestion control and flow scheduling, respectively. The MAC layer implements link scheduling and a TDMA MAC protocol. The organization of these modules into host OS kernel and network interface card firmware depends on the architecture used. For convenience, Figure 2-3 shows this organization on testbed devices, where the full MAC firmware resides on the wireless cards while the upper layers reside in the host OS kernel. In the figure, diamonds represent packet classifiers, while circles represent packet schedulers. The data flow from left to right are outgoing packets originating from the applications to the wireless medium; the data flow in the opposite direction are incoming packets that are routed or delivered to the applications. Packets in the slotted wireless medium (far right), which are neither incoming nor outgoing, represent transmissions between two other nodes in the network.

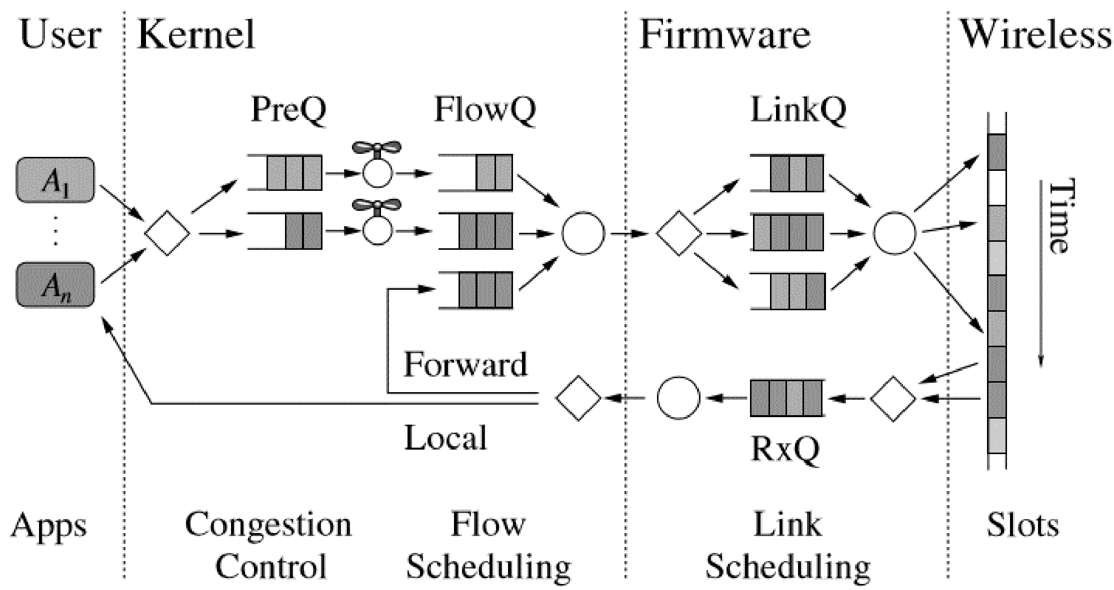

Figure 2-3 Xpress Data Plane

(Source:Remya K et al.,2015)

2.2.3 Xpress-Control Plane

The different system components must exchange control information to coordinate the network-wide transmissions. Figure 2-4 depicts the XPRESS control plane with its different components at the mesh controller (MC) and a mesh access point (MAP). The uplink control channel is represented by the arrows labeled from 1 to 3, while the downlink control channel is represented by arrows 4 and 5. There is also an internal control channel (dashed arrow) between the MAC and the the kernel packet scheduler, to synchronize them with respect to time and link queue (LinkQ) state.

Uplink channel: Each node runs an actuator application that communicates with the controller application at the MC. A schedule computation cycle begins at the start of a new frame. At this point, the TDMA MAC protocol notifies the actuator about the new frame and piggybacks in the same message the link statistics collected during the last frame (e.g., received signal strength and delivery ratio). This is the Step 1 in Figure 2-4. The actuator then collects the FlowQ lengths (Step 2), combines all information and sends it to the MC using the uplink channel (Step 3).

Mesh controller (MC): The zoom of the MC in Figure 2-4 shows the different steps taken for the calculation of a TDMA frame schedule composed of N slots. First, the link statistics are used to estimate the network state, namely, interference relations and link loss rates.

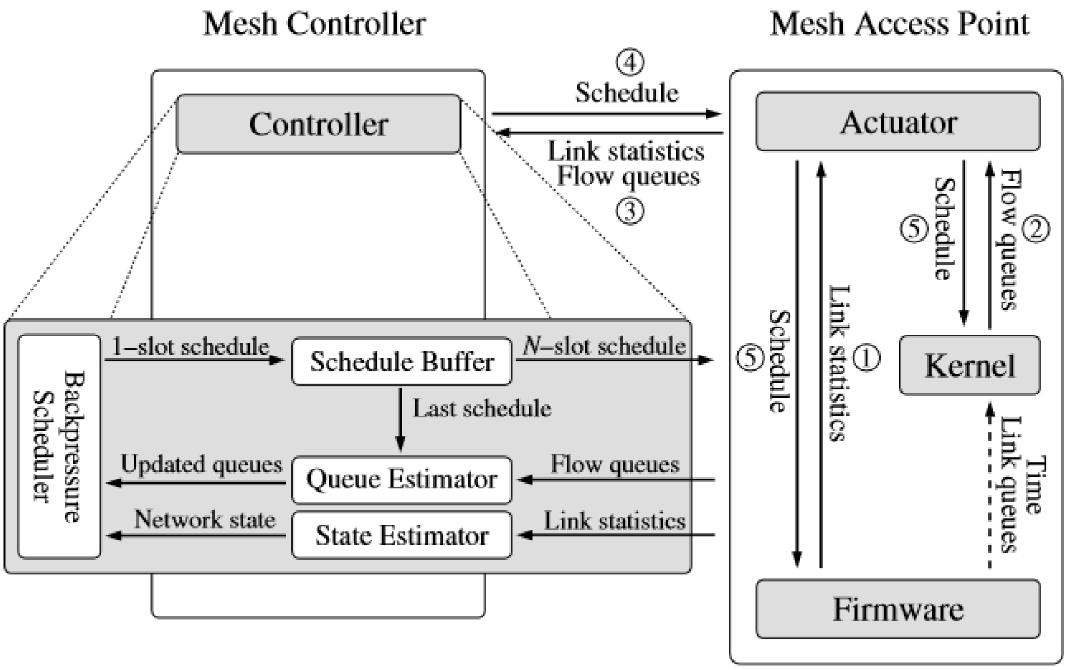

Figure 2-4 Express Control Plane

(Source:Remya K et al.,2015)

The FlowQ lengths are also collected and fed into a Back Pressure scheduler. The scheduler then uses the FlowQ lengths and network state to compute the network schedule, using the Back Pressure algorithm and speculative scheduling technique.

Downlink channel: When the schedule computation is finished, the MC disseminates the new schedule using the downlink control channel (Step 4). The actuator receives this packet and forwards the new schedule both to the OS kernel as well as to the MAC layer (Step 5). The TDMA MAC starts using this new schedule for data transmission in the next frame. Packets will then be dequeued from the FlowQs to the LinkQs in accordance with this new schedule.

2.2.4 Back Pressure Scheduler

XPRESS introduces a speculative scheduling technique to reduce scheduling overhead. This technique computes a schedule for a group of slots on a TDMA frame basis and performs the optimal Back Pressure computation for all slots in the frame based on speculated network queue state [9]. Figure 2-5 depicts the speculative scheduling operation. At the start of TDMA frame k, the MC computes a schedule S(k + 1) for all data slots of the next frame k + 1. This approach provides the MC with a time budget of one TDMA frame to perform optimal computations. However, it comes at the expense of uncertainty due to changes in the queue backlogs during frame k. These changes are due to incoming packets at the source node of each flow, wireless losses, and the schedule S(k) executed by the nodes during the slots of frame k. The MC addresses this uncertainty using the schedule S(k) it computed during the previous frame k−1, as well as the FlowQ lengths Q(k) and source rate estimates R(k) provided by the mesh nodes at the start of frame k. Additionally, the scheduler uses only links of high packet delivery ratios which reduces the uncertainty of wireless losses.

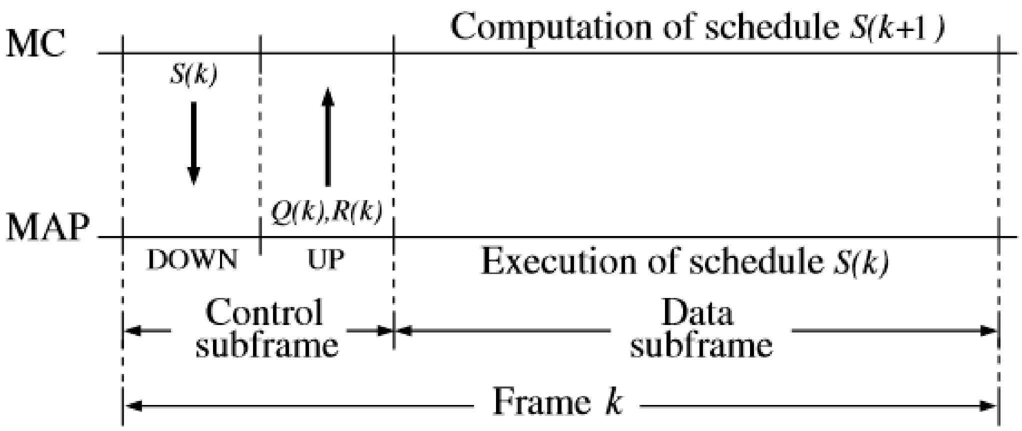

Figure 2-5 Xpress Back Pressure Scheduler
(Source:Remya K et al., 2015)

The MC computes an estimate Q(k+1) of the queue backlogs at the start of frame k +1. The MC updates Q(k) by adding R(k) to the flow queue of each source node as an estimate of the number of incoming packets at frame k. Then, the MC locally emulates the transmissions of schedule S(k) on this updated queue state, that is, for each slot, the scheduled FlowQs of transmitters are decremented and the FlowQs of receivers are incremented until Q(k + 1) is obtained. Given Q(k + 1), the MC computes the schedule of the first slot of frame k + 1 with the Back Pressure algorithm. After this computation, the MC updates the scheduled FlowQs, creating a new queue estimate for the second slot (see Figure 2-4). The rate R(k) is also used to update the queue estimate of each slot according to the input rate at each source. With the new queue estimate, the Back Pressure algorithm computation is repeated. This process continues for the following slots, until the schedule S(k +1) of all data slots of frame k+1 are calculated. After the computation, the MC transmits this schedule to the mesh nodes for execution during frame k + 1. Experimental validation of speculative scheduling technique show that the estimated queue backlog Q closely follows the actual backlog Q.

Chapter 3 Methodology

3 METHODOLOGY

As MANET is being used only under experimental conditions so in this research the modelling of routing protocol has been done using NS-3 simulator which offers various option for MANET networks as discussed in chapter 4. A different routing model was devised and techniques to optimize the Back Pressure algorithm to make it delay efficient and energy efficient were implemented. This was done in two main parts.

3.1 Modify Back Pressure routing algorithm

The Back Pressure Routing algorithm was modified in order to get BWAR (Back Pressure with adaptive redundancy). This part is important to minimize delay. of Back Pressure Routing.

The Figure 3-1 shows the class diagram used in NS-3 simulator for implementing Back Pressure routing with adaptive redundancy.

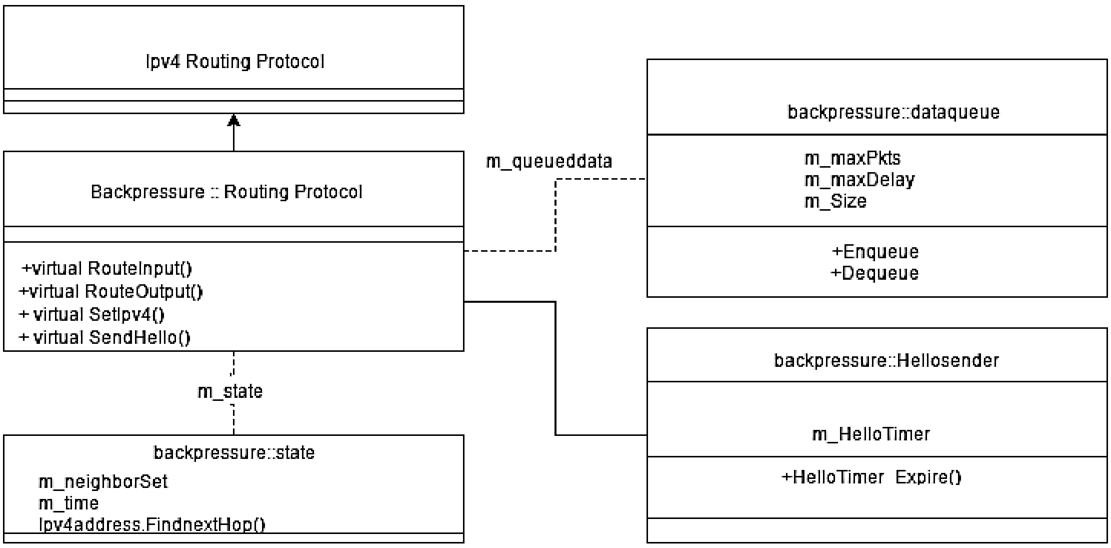

Figure 3-1 BWAR modelling in NS3

The following Steps are implemented in the main module definition of Back Pressure routing protocol with adaptive redundancy.

- RouteOutput is called whenever upper layers have an outbound packet and returns the loopback address
- RouteOutput is merely used to send each data packet to the RouteInput function
- Then RouteInput is called when a packet is received from upper/lower layers
- RouteInput queues incoming data packet in a data queue
- A FIFO Data Queue is located at the routing layer

- WiFi MAC Queue default behavior is changed: it stores a few unicast data packets and Hello Broadcast control packets
- Data Packets would remain trapped at Routing Data Queues
- Whenever there are free data packet slots in the WiFi MAC Queue send a potential transmission opportunity to the routing layer
- If the Routing Data Queue is not empty call FindNextHop function

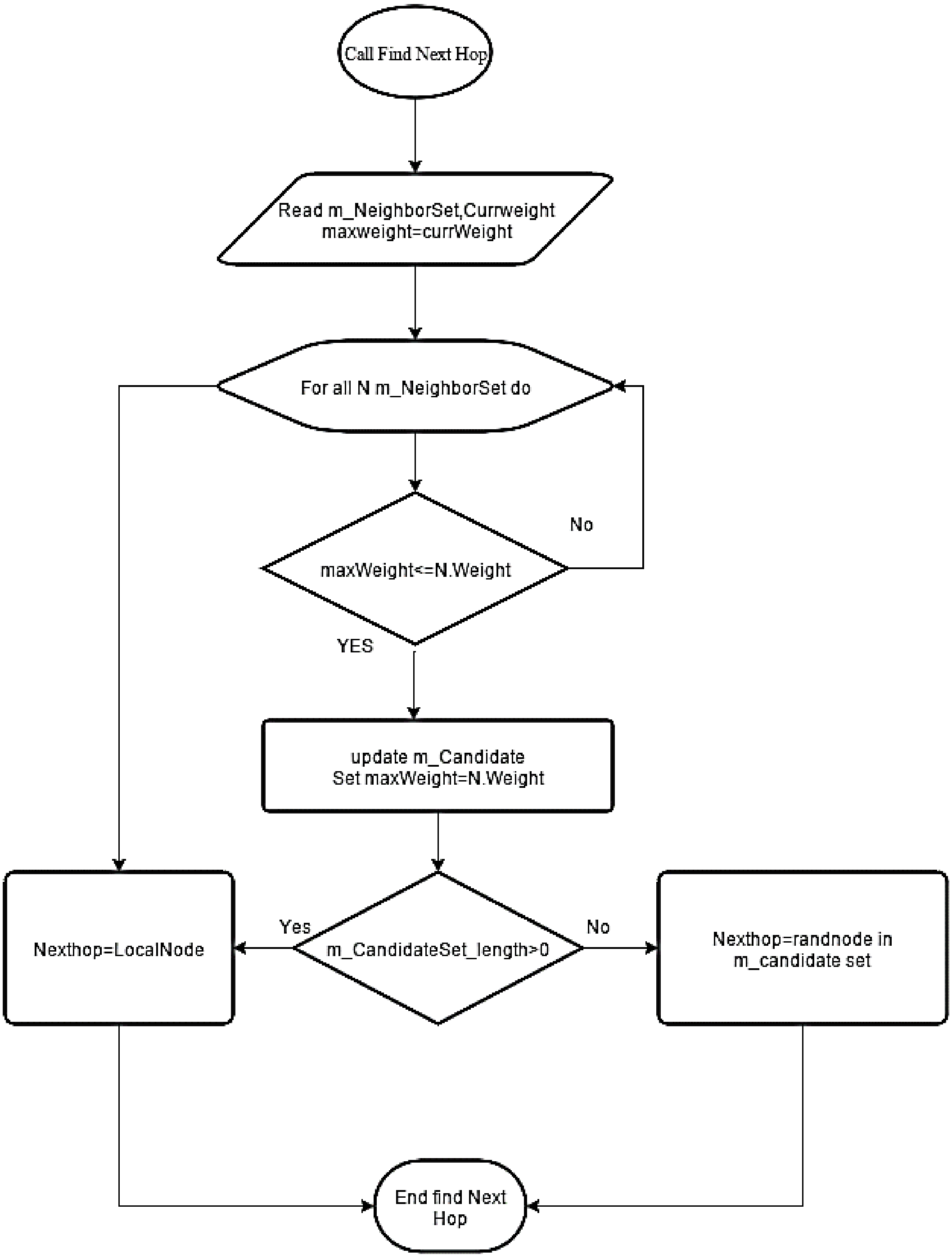

Figure 3-2 Flowchart for BWAR

3.2 Implement Crosslayer architecture over BWAR

Cross Layer architecture when implemented over BWAR increases energy efficiency of routing protocol. Implementing cross layer structure over BWAR we get the proposed model of Modified Back Pressure Routing.

The following Steps are used to implement Cross Layer Architecture

- In Cross Layer Back Pressure, as each node saves its current sequence number in MAC sub-layer, the sequence number is synchronized to one saved in routing sub-layer. The two sequence numbers are updated simultaneously.
- Cross Layer Back Pressure sets a field in the headers of all data frames. The field is utilized to the current sequence number of the node.
- It is used in MAC sub-layer and as the network is not being grouped, the field is placed in Address4 field of BSSID in frame headers.
- When MAC sub-layer receives a data frame from a neighbor, whether the node is or not is the destination, it transmits the neighbor's MAC address and the newest sequence number in the frame to the routing sub-layer.
- The route table of routing sub-layer adds a field: the MAC address of the destination.
- If a node receives the MAC address and the newest sequence number of a neighbor, it updates the according fields of its route table.
- In other cases, routing sub-layer controls the sending and processing of HELLO messages. But in Cross Layer Back Pressure, MAC sub-layer controls it. And the formats of HELLO messages frames are decreased. There are frame headers and frame tails, but no frame bodies.
- HELLO messages are sent as follows: After the last data frame is sent, every HELLO_INTERVAL, the node sends a HELLO message

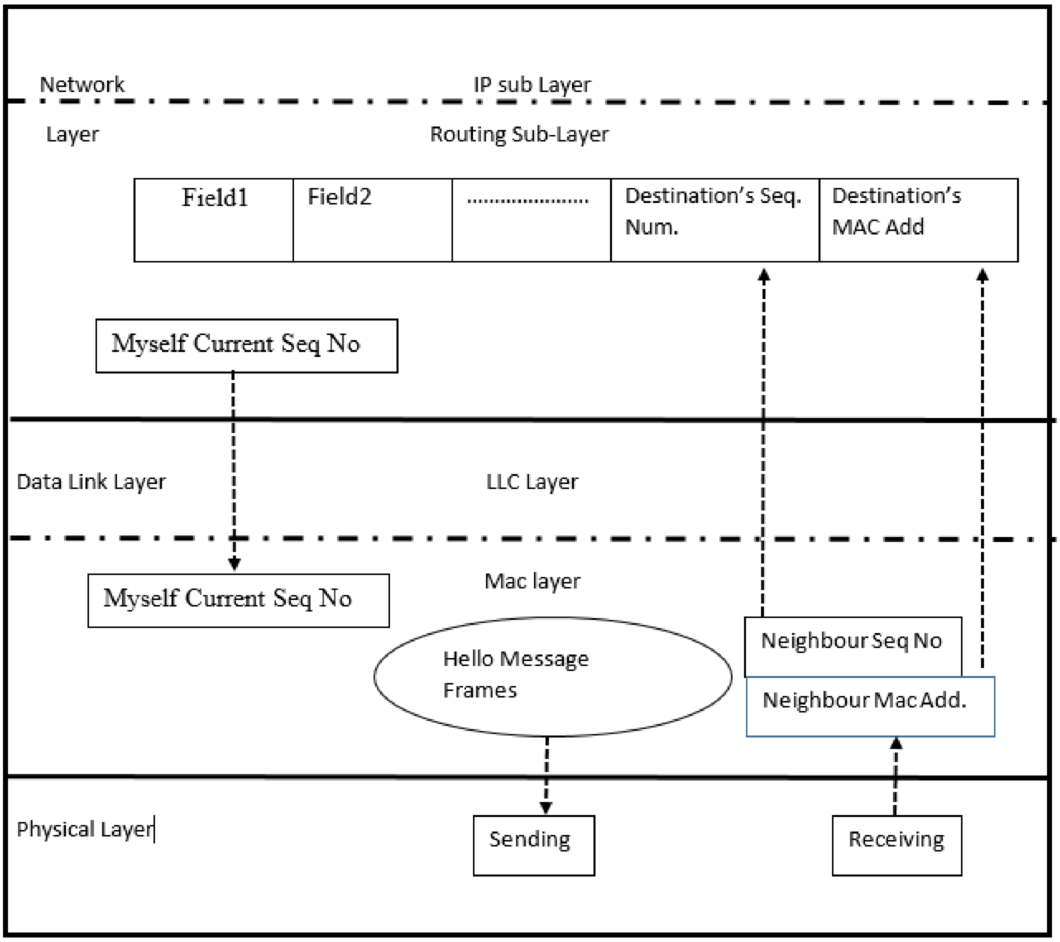

Figure 3-3 Crosslayer Back Pressure Implementation

The Figure 3-3 shows the implementation block of Crosslayer Routing including Network Layer and Mac Layer. The Myself Current Seq. number are synchronized as in Mac layer and Network Layer. Similarly, Neighbor Sequence number and Neighbor Mac address are updated by Mac layer to Network Layer.

CHAPTER 4 SYSTEM MODEL

4 SYSTEM MODEL

The models for Crosslayer Architecture and BWAR are also dependent on other models underlying in NS3 Some of the important models are briefly discussed below.

4.1 Propagation Loss Model

The Friis transmission equation is used in telecommunications engineering, and gives the power received by one antenna under idealized conditions given another antenna some distance away transmitting a known amount of power.

The Friis transmission equation is as follows. Given two antennas, the ratio of power available at the input of the receiving antenna, P_r, to output power to the transmitting antenna, P_t, is given by

$P_r=P_tG_tG_r(\lambda/4\pi R)^2$ ……………………………………………………………..5

where G_t and G_r are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas respectively, λ is the wavelength, and R is the distance between the antennas. The inverse of the third factor is the so-called free-space path loss.

Friss propagation loss model is implemented as a subclass under propagation loss in NS-3.

4.2 Random Waypoint Model

In mobility management, the random waypoint model is a random model for the movement of mobile users, and how their location, velocity and acceleration change over time. Mobility models are used for simulation purposes when new network protocols are evaluated..It is one of the most popular mobility models to evaluate mobile ad hoc network (MANET) routing protocols, because of its simplicity and wide availability.

In random-based mobility simulation models, the mobile nodes move randomly and freely without restrictions. To be more specific, the destination, speed and direction are all chosen randomly and independently of other nodes. This kind of model has been used in many simulation studies.

Two variants, the random walk model and the random direction model are variants of the random waypoint model. Random waypoint mobility model is a subclass under mobility model class defined in NS-3.

4.3 Energy Framework Model

Energy consumption is a key issue for wireless devices, and wireless network researchers need to investigate the energy consumption at a node or in the overall network while running network simulations in NS-3. Further, as concepts such as fuel cells and energy scavenging are becoming viable for low power wireless devices, incorporating the effect of these emerging technologies into simulations has support for modeling diverse energy sources in NS-3. The NS-3 Energy Framework provides the basis for energy consumption, energy source and energy harvesting modeling.

The NS-3 Energy Framework is composed of 3 parts: Energy Source, Device Energy Model and Energy Harvester.

4.3.1 Energy Source

The Energy Source represents the power supply on each node. A node can have one or more energy sources, and each energy source can be connected to multiple device energy models. Connecting an energy source to a device energy model implies that the corresponding device draws power from the source. The basic functionality of the Energy Source is to provide energy for devices on the node. When energy is completely drained from the Energy Source, it notifies the devices on node such that each device can react to this event. Further, each node can access the Energy Source Objects for information such as remaining energy or energy fraction (battery level). This enables the implementation of energy aware protocols in NS-3.

In order to model a wide range of power supplies such as batteries, the Energy Source must be able to capture characteristics of these supplies. There are 2 important characteristics or effects related to practical batteries:

Rate Capacity Effect

Decrease of battery lifetime when the current draw is higher than the rated value of the battery.

Recovery Effect

Increase of battery lifetime when the battery is alternating between discharge and idle states.

In order to incorporate the Rate Capacity Effect, the Energy Source uses current draw from all the devices on the same node to calculate energy consumption. Moreover, multiple Energy Harvesters can be connected to the Energy Source in order to replenish its energy. The Energy Source periodically polls all the devices and energy harvesters on the same node to calculate the total current drain and hence the energy consumption. When a device changes state, its corresponding Device Energy Model will notify the Energy Source of this change and new total current draw will be calculated. Similarly, every Energy Harvester update triggers an update to the connected Energy Source.

The Energy Source base class keeps a list of devices (Device Energy Model objects) and energy harvesters (Energy Harvester objects) that are using the particular Energy Source as power supply. When energy is completely drained, the Energy Source will notify all devices on this list. Each device can then handle this event independently, based on the desired behavior that should be followed in case of power outage.

4.3.2 Device Energy Model

The Device Energy Model is the energy consumption model of a device installed on the node. It is designed to be a state based model where each device is assumed to have a number of states, and each state is associated with a power consumption value. Whenever the state of the device changes, the corresponding Device Energy Model will notify the Energy Source of the new current draw of the device. The Energy Source will then calculate the new total current draw and update the remaining energy.

The model can also be used for devices that do not have finite number of states. For example, in an electric vehicle, the current draw of the motor is determined by its speed. Since the vehicle's speed can take continuous values within a certain range, it is infeasible to define a set of discrete states of operation. However, by converting the speed value into current directly, the same set of Device Energy Model APIs can still be used.

4.3.3 Energy Harvester

The energy harvester represents the elements that harvest energy from the environment and recharge the Energy Source to which it is connected. The energy harvester includes the complete implementation of the actual energy harvesting device (e.g., a solar panel) and the environment (e.g., the solar radiation). This means that in implementing an energy harvester, the energy contribution of the environment and the additional energy requirements of the energy harvesting device such as the conversion efficiency and the internal power consumption of the device needs to be jointly modeled.

4.3.4 WiFi Radio Energy Model

The WiFi Radio Energy Model is the energy consumption model of a Wifi net device. It provides a state for each of the available states of the PHY layer: Idle, CcaBusy, Tx, Rx, ChannelSwitch, Sleep. Each of such states is associated with a value (in Ampere) of the current draw (see below for the corresponding attribute names). A Wifi Radio Energy Model PHY Listener is registered to the Wifi PHY in order to be notified of every Wifi PHY state transition. At every transition, the energy consumed in the previous state is computed and the energy source is notified in order to update its remaining energy.

The Wifi Tx Current Model gives the possibility to compute the current draw in the transmit state as a function of the nominal tx power (in dBm), as observed in several experimental measurements. To this purpose, the Wifi Radio Energy Model PHY Listener is notified of the nominal tx power used to transmit the current frame and passes such a value to the Wifi Tx Current Model which takes care of updating the current draw in the Tx state. Hence, the energy consumption is correctly computed even if the Wifi Remote Station Manager performs per-frame power control. Currently, a Linear Wifi Tx Current Model is implemented which computes the tx current as a linear function (according to parameters that can be specified by the user) of the nominal tx power in dBm.

The Wifi Radio Energy Model offers the possibility to specify a callback that is invoked when the energy source is depleted. If such a callback is not specified when the Wifi Radio Energy Model Helper is used to install the model on a device, a callback is implicitly made so that the Wifi PHY is put in the SLEEP mode (hence no frame is transmitted nor received afterwards) when the energy source is depleted. Likewise, it is possible to specify a callback that is invoked when the energy source is recharged (which might occur in case an energy harvester is connected to the energy source). If such a callback is not specified when the Wifi Radio Energy Model Helper is used to install the model on a device, a callback is implicitly made so that the Wifi PHY is resumed from the SLEEP mode when the energy source is recharged.

4.4 Flow Monitor Model

The Flow Monitor module goal is to provide a flexible system to measure the performance of network protocols. The module uses probes, installed in network nodes, to track the packets exchanged by the nodes, and it will measure a number of parameters. Packets are divided according to the flow they belong to, where each flow is defined according to the probe's characteristics (e.g., for IP, a flow is defined as the packets with the same {protocol, source (IP, port), destination (IP, port)} tuple. The statistics are collected for each flow can be exported in XML format

4.5 Simulation Parameters

Table 4-1 Simulation Parameters

Wireless Technology	802.11 Wifi
Visualizer	Netanim Animator
Mobility Model	Random waypoint mobility model
Propagation Loss	Friss propagation Loss model
Network type	IPv4
Number of Nodes	10 to 70 with difference of 10
Simulation Time	5 minutes
Routing protocols compared	AODV,DSDV,DSR,Back Pressure,Modified Back Pressure
Simulation Area	100 Sq m

4.6 Simulation

The MANET network is simulated using NS3 simulator and various existing routing protocols are compared with modified Back Pressure routing.

In all the cases the mobility model used is Random Waypoint Model and Friss Propagation Loss model is used for propagation. These models are already defined in the class libraries of NS3.Below is the snapshot of Netanim animator which was used to visualize the simulation of NS3 generated csv files

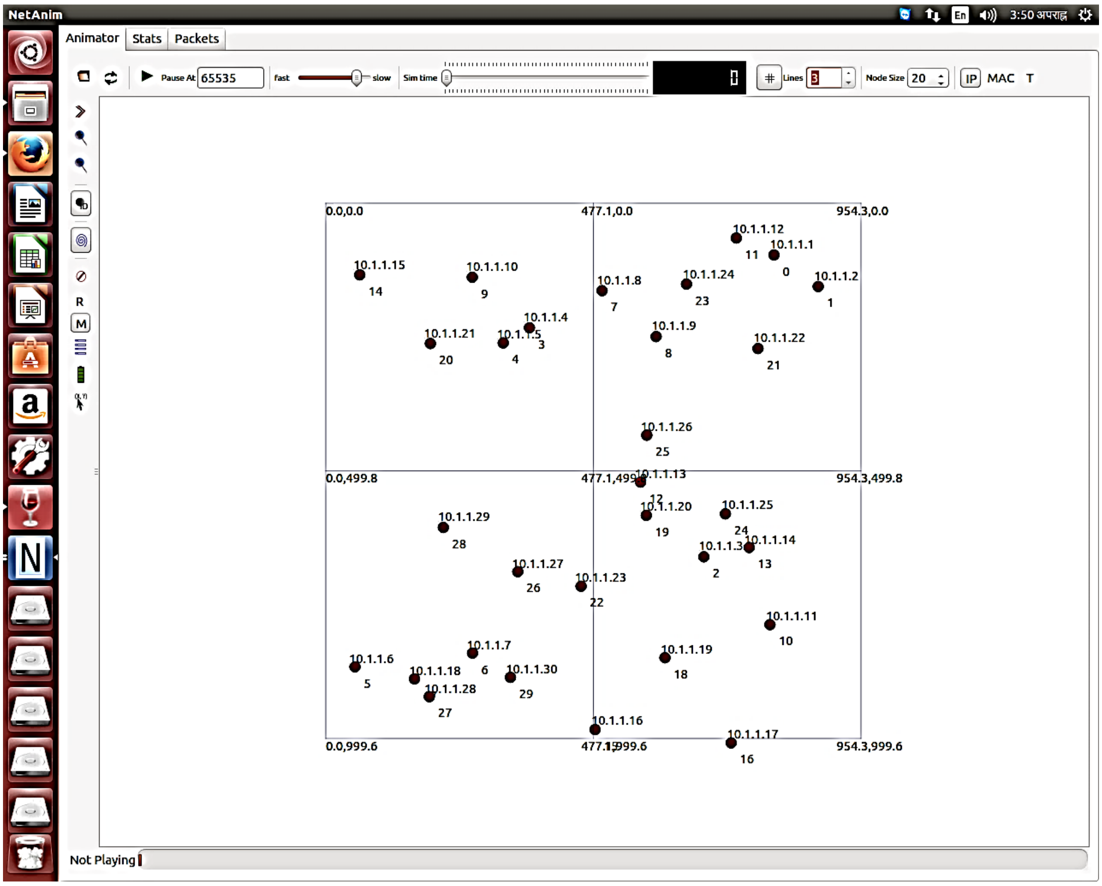

Figure 4-1 Ad-Hoc network Simulation scenario with 30 nodes

Chapter 5 : Result, Comparision and Analysis

5 RESULTS, COMPARISION AND ANALYSIS

5.1 Results and Comparison

5.1.1 Delay Performance

From Figure 5-1 we can compare the delay performance of AODV and proposed algorithm. The packet transmission delay for AODV is found to be better with lower number of nodes but as the no of nodes increases beyond 40 proposed model has better performance of delay characteristics The delay is nearly the same when the no of nodes lies between 40 to 50. The delay characteristic of proposed algorithm seems slightly better compared to AODV routing.

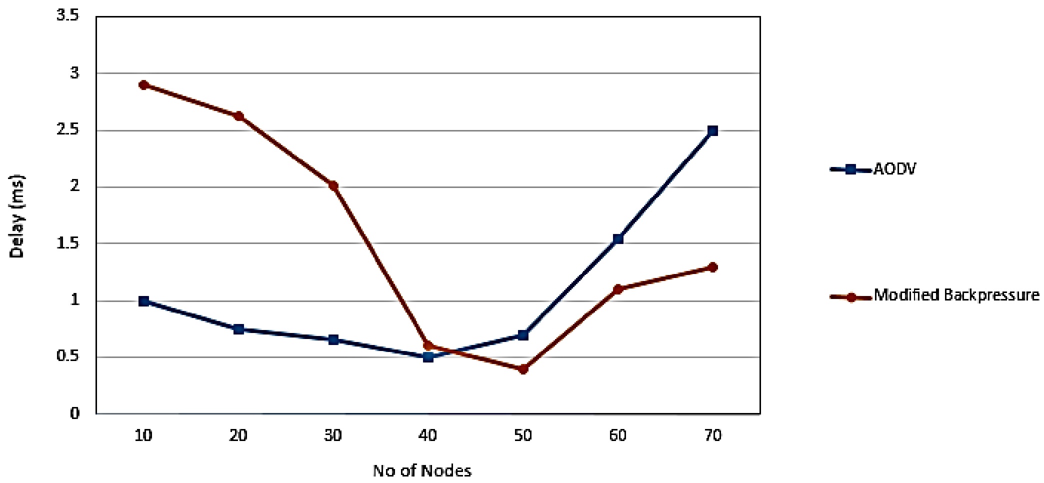

Figure 5-1 Delay comparison of AODV and Modified Back Pressure

Similarly, the packet transmission delay parameter for Back Pressure and Modified Back Pressure algorithm can be compared from Figure 5-2.The proposed algorithm which is the modification of Back Pressure algorithm has better performance irrespective of no of nodes As the Back Pressure algorithm has higher delay at lower no of nodes proposed algorithm is even better when the no of nodes are small.

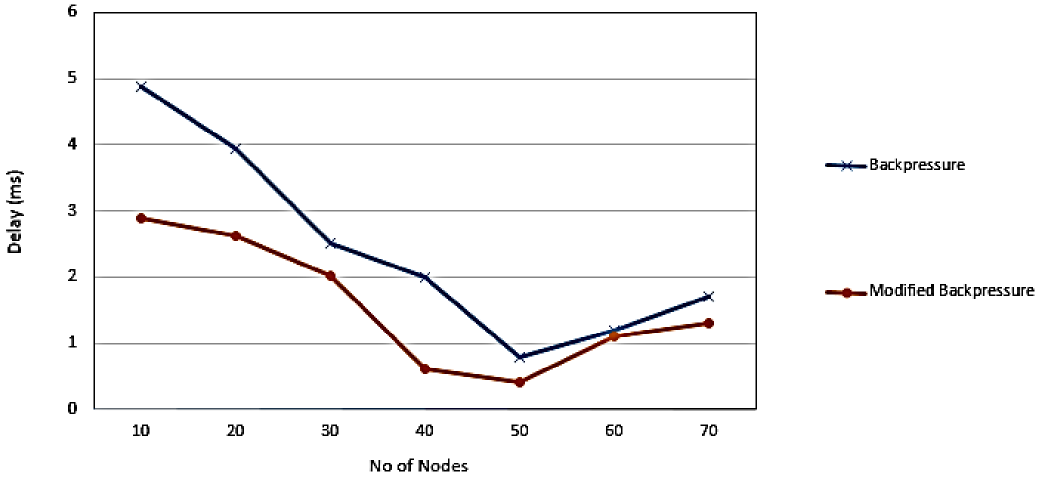

Figure 5-2 Delay comparison of Back Pressure and Modified Back Pressure

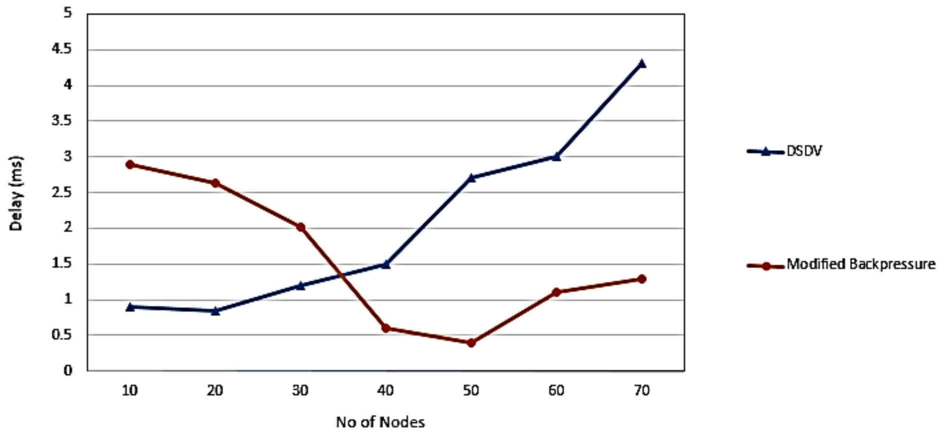

Figure 5-3 Delay Comparison of DSDV and Modified Back Pressure

The Figure 5-3 shows the delay comparison of DSDV and proposed algorithm. The DSDV routing protocol the delay seems to nearly exponential increase after certain threshold of nodes and thus seems impractical with higher no of nodes It shows good performance when the no of nodes is smaller with delay value below 1 ms. With proposed algorithm the similar delay is obtained with no of nodes between 40 and 50

The delay comparison of DSR and proposed routing is shown in Figure 5-4. The modified Back Pressure simply outperforms the DSR routing The delay of proposed algorithm is always less than that of DSR irrespective of the no of nodes

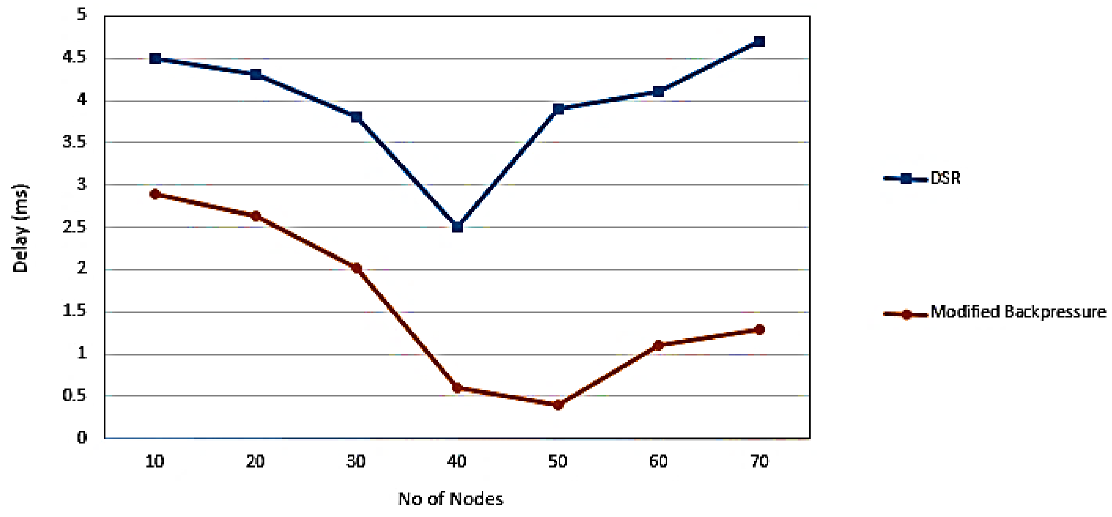

Figure 5-4 Delay Comparison of DSR and Modified Back Pressure

5.1.2 Energy Performance

The energy performance of AODV and Proposed algorithm can be compared using Figure 5-5. The energy consumption increases significantly with AODV routing but for modified Back Pressure it is nearly flat Energy performance of proposed algorithm is simply better compared to AODV.

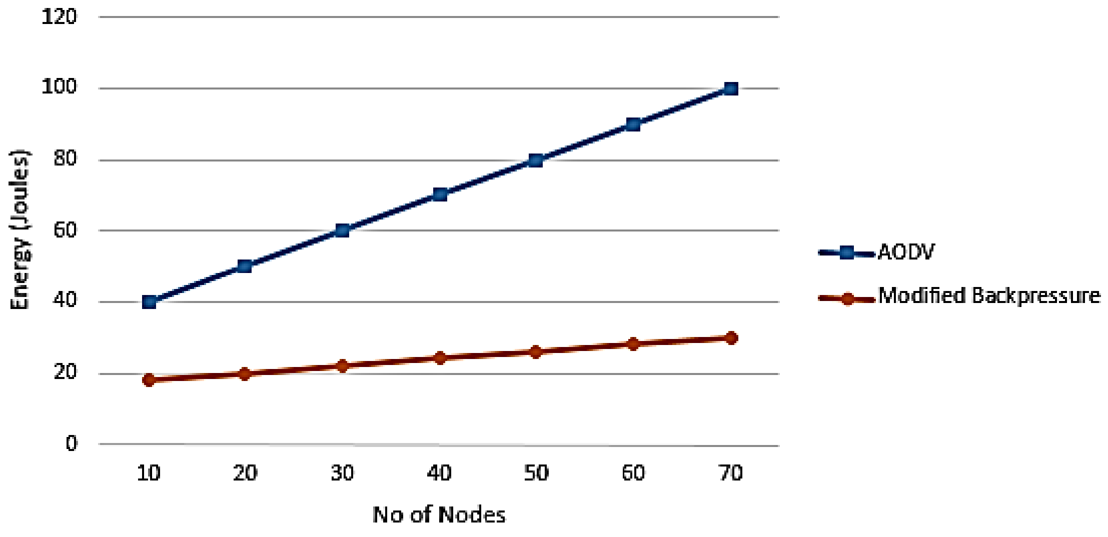

Figure 5-5 Energy comparison of AODV and Modified Back Pressure

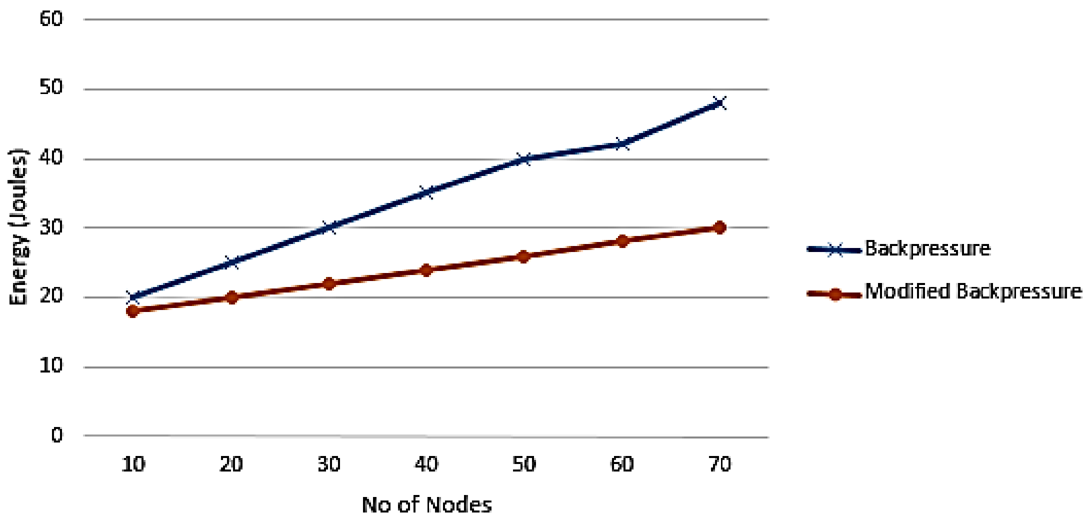

Figure 5-6 Energy Comparison of Back Pressure and Modified Back Pressure

The energy performance of proposed algorithm is better than Back Pressure algorithm as shown in Figure 5-6.When the no of nodes is 10 they seem to consume same amount of energy but when the no of nodes reaches 70 the difference of energy consumption is nearly 20J.So the modified algorithm is better compared to original algorithm.

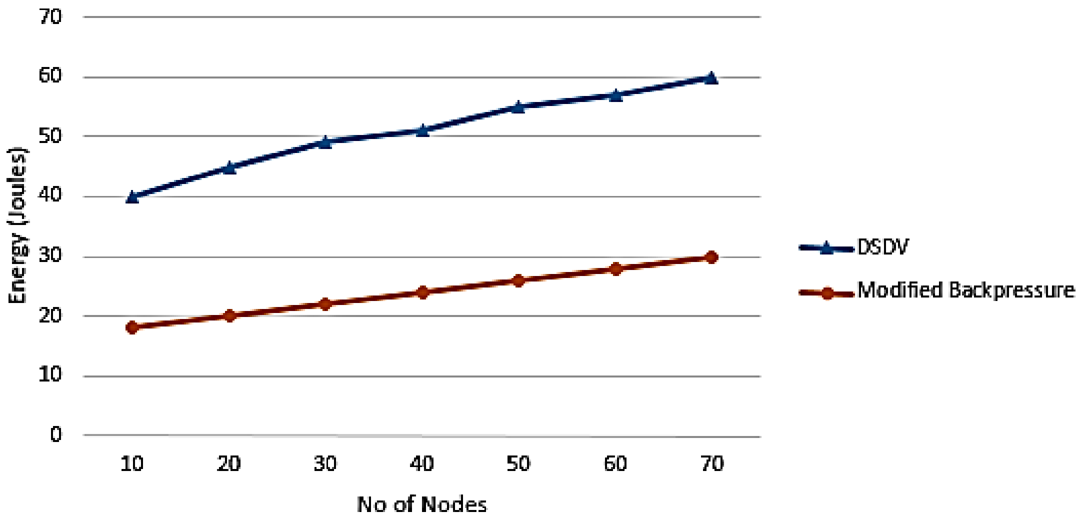

Figure 5-7 Energy Comparison of DSDV and Modified Back Pressure

From Figure 5-7 it can be easily known that the proposed model is better compared to DSDV routing. It simply outperforms DSDV routing

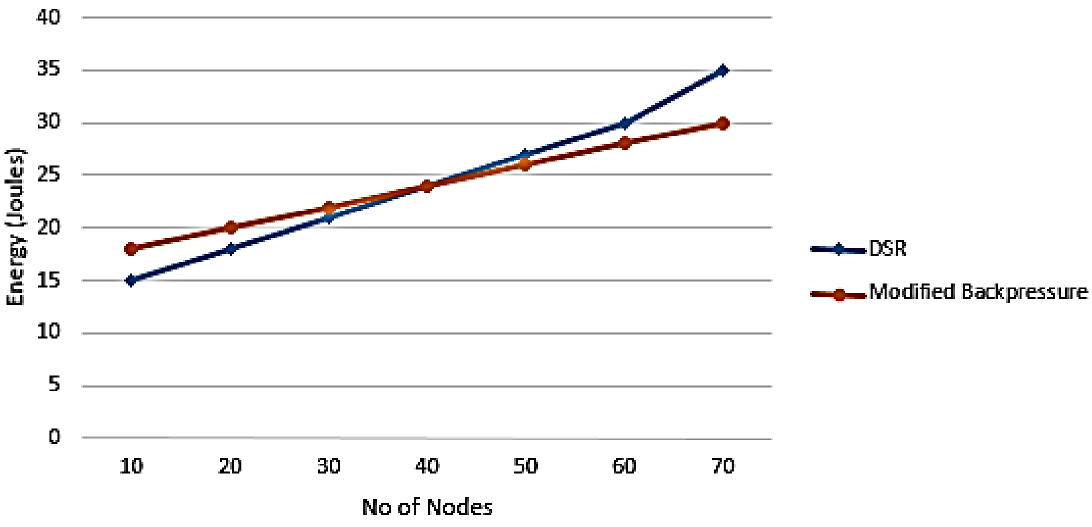

Figure 5-8 Energy Comparison of DSR and Modified Back Pressure

The energy comparison of DSR and proposed algorithm is nearly same as shown in Figure 5-8 But when the no of nodes increases beyond 50 the proposed model seems to be slightly better than DSR routing.

5.2 Analysis

From the above discussion regarding delay comparison of proposed model and existing model overall performance comparison can be finally visualized.

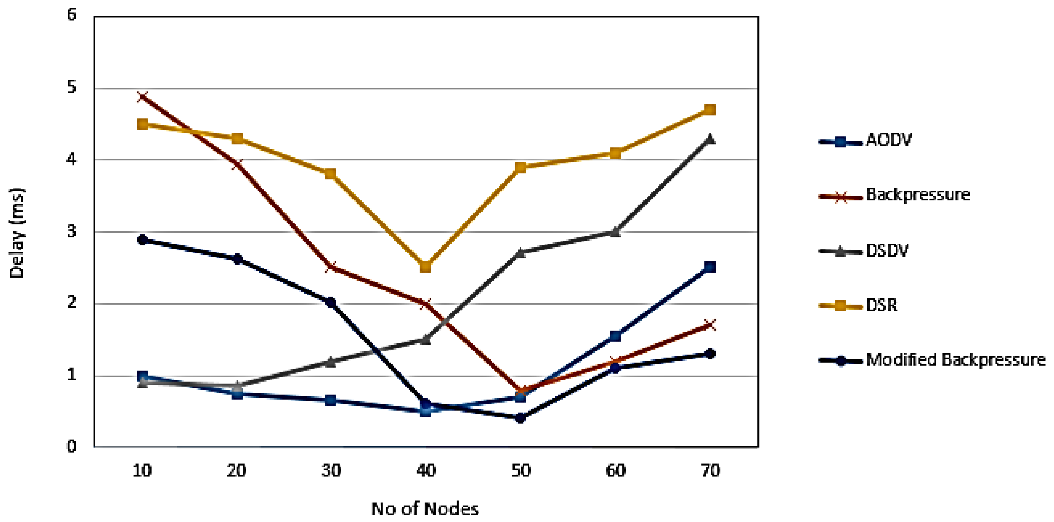

Figure 5-9 Delay performance of various routing models

The Figure 5-9 shows the delay characteristics of various MANET routing protocols. The Packet delivery time or delay is one of the most important characteristics of data transfer. The faster a packet is delivered more the number of data can be transmitted in a certain time.

Most of the routing protocols performed well for when the number of nodes is around 30 to 50. AODV routing protocol has the minimum delay when the no of nodes is 50 and is less than 1 ms. This protocols delay seems to increase significantly when the no of nodes starts to rise above 50. The modified Back Pressure routing model is found out to be the best for a larger range of nodes around 20 to 70 in similar condition.

On the other hand, DSR routing protocol seems to be working fine only for the mid-range of 30 to 50 nodes. Its delay increases towards both ends of the graph, Also DSDV is good in handling lower number of nodes but as the nodes increases its performance degrades too.

In case of Back Pressure and modified Back Pressure the delay is much higher when the nodes are less because they the pressure is handled better with initial heavy loading of data. The modified Back Pressure routing is better compared to all other protocols.

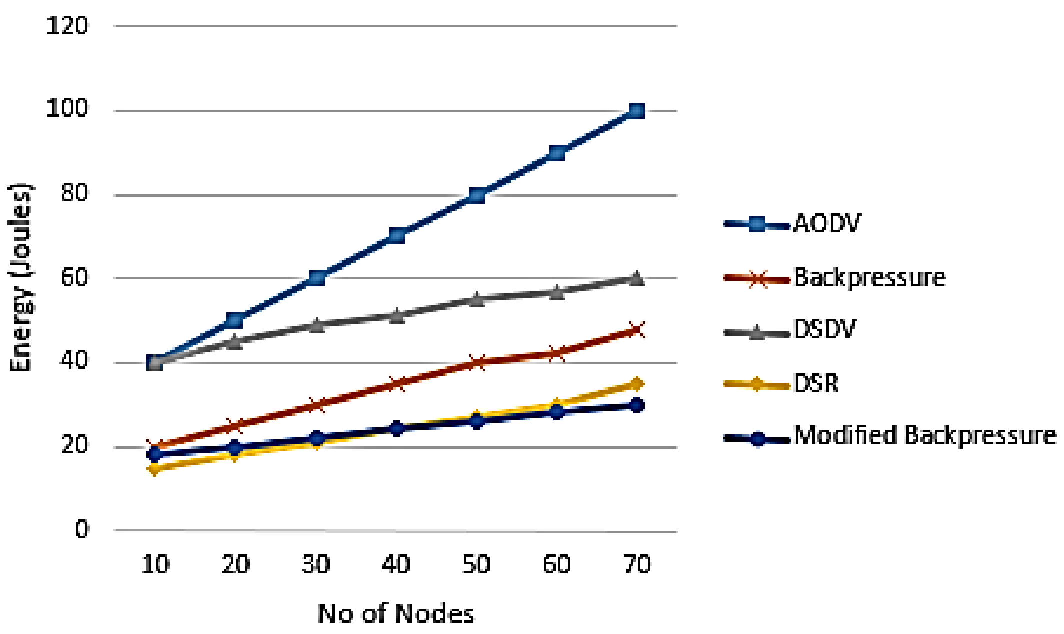

Figure 5-10 Energy Consumption comparison of Routing protocols

The Figure 5-10 shows the result of energy consumption simulation of various routing protocols in NS3. It shows the energy comparison of routing protocols AODV, DSDV, DSR, Back Pressure, Modified Back Pressure.

In AODV protocol energy consumption is found to increase nearly linearly with respect to the increase in nodes It is worst compared to modified Back Pressure routing. DSDV and DSR are better as compared to AODV but the DSR seems to be the best routing compared to others.

The proposed routing Modified Back Pressure seems to be near to DSR routing technique with performance slightly lower at less no of nodes as compared to DSR but as the number of nodes increase Modified Back Pressure is the best routing with respect to energy consumption.

Chapter 6 Conclusion

6 CONCLUSION

6.1Conclusion

The comparison and analysis clearly show that the Modified Back Pressure Routing that introduces cross layer and adaptive redundancy is best routing among existing routing. It has been analytically proven that this algorithm is also energy optimal while providing a better delay. Through simulation result, it has been shown that modified Back Pressure outperforms both traditional Back Pressure (at low loads) and conventional DTN-routing mechanisms (at high loads) in encounter-based mobile networks.

Thus it can be decided that QoS parameters of delay and Energy are optimized by the proposed Routing. The Modified Back Pressure Routing has very high efficiency in delay as compared to existing routing protocols it can replace other routing protocols in all aspects of ad hoc networks such as VANETS and WSNs. In future, research could be done in order to incorporate more QoS parameters like jitter and latency

References

REFERENCES

[1] Tomas Krag and Sebastian Büettrich (2004-01-24). "*Wireless Mesh Networking*". O'Reilly Wireless Dev Center. Retrieved 2009-01-20.

[2] Zanjireh, M.M.; Shahrabi, A.; Larijani, H., "ANCH: A New Clustering Algorithm for Wireless Sensor Networks," in *Advanced Information Networking and Applications Workshops (WAINA)*, 2013 27th International Conference on , vol., no., pp.450-455, 25-28 March 2013

[3] Crow, B. P., Widjaja, I., Kim, J. G., & Sakai, P. T. (1997). IEEE 802.11 "Wireless Local Area Networks". *Communications Magazine*, IEEE, 35(9), 116-126

[4] Abolhasan, M., Wysocki, T., & Dutkiewicz, E. (2004). "*A review of routing protocols for mobile ad hoc networks. Ad hoc networks*", 2(1), 1-22..

[5] Bansal, Meenakshi, Rachna Rajput, and Gaurav Gupta. "Mobile ad hoc networking (MANET): Routing protocol performance issues and evaluation considerations." *The internet society* (1999).

[6] Allard, G., Minet, P., Nguyen, D. Q., & Shrestha, N. (2006). "Evaluation of the energy consumption in MANET." *In Ad-Hoc, Mobile, and Wireless Networks* (pp. 170-183). Springer Berlin Heidelberg.

[7] Remya K, Sangeetha C P and C D Suriyakala ," QoS Improvement in Mobile Ad Hoc Networks Using Cross Layer Optimization" *IJAREEIE Vol. 4*, Special Issue 1, March 2015

[8] Rafael Laufer, , Theodoros Salonidis, Henrik Lundgren, and Pascal Le Guyadec "A Cross-Layer Back Pressure Architecture for Wireless Multihop Networks" *IEEE/ACM Transactions on networking*, VOL. 22, NO. 2, APRIL 2014

[9] Majed Alresaini, Maheswaran Sathiamoorthy, Bhaskar Krishnamachari, Michael J. Neely "Back Pressure with Adaptive Redundancy (BWAR)" *IEEE Infocom* 2012