PERFORMANCE IMPROVEMENT FOR MOBILE AD HOC COGNITIVE PACKETS NETWORK

by

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Abstract

In this thesis, focusing on the quality of service (QoS) improvement using per-packet power control algorithm in Ad Hoc Cognitive Packet Networks (AHCPN). A power control mechanism creates as a network-assisted function of ad hoc cognitive packet-based routing and aims at reducing both energy consumption in nodes and QoS requirements. The suggested models facilitate transmission power adjustments while also taking into account the effects on network performance.

The thesis concentrate on three main contributions. **Firstly**, a power control algorithm, namely the adaptive Distributed Power management algorithm (DISPOW) was adopted. Performance of DISPOW was compared to existing mechanisms and the results showed 27, 13, 9, and 40 percent improvements in terms of Delay, Throughput, Packet Loss, and Energy Consumption respectively.

Secondly, the DISPOW algorithm was enhanced, namely a Link Expiration Time Aware Distributed Power management algorithm (LETPOW). This approach periodically checks connectivity, transmission power, interference level, routing overhead and Node Mobility in AHCPN. The results show that LETPOW algorithm improves the performance of system. Results show further improvement from DISPOW by 30,25,30,42 percent in terms of delay, packet loss ratio , path lengths and energy consumption respectively.

Finally,Hybrid Power Control Algorithm (HLPCA) has presented is a combination of Link Expiration Time Aware Distributed Power management algorithm (LETPOW) and Load Power Control Algorithm (LOADPOW); deal with cross-layer power control applied for transmitting information across the various intermediate layers. LOADPOW emphasis on the concept of transmission Power, Received Signal Strength Indication (RSSI), and the suitable distance between the receiver and the sender. The proposed algorithm outperforms DISPOW and LETPOW by 31,15,35,34,44 percent in terms of Delay, Throughput, Packet Loss,path length and Energy Consumption respectively. From this work, it can be concluded that optimized power control algorithm applied to Ad-hoc cognitive packet network results in significant improvement in terms of energy consumption and QoS.

To, my Father and Mother

brothers and sisters

wife

sons Mohammed and Hasan.

Declaration

I declare that this thesis is my own work and is submitted for the first time to the Post-Graduate Research Office. The study was originated, composed and reviewed by myself and my supervisors in the Department of Electronic and Computer Engineering, College of Engineering, Design and Physical Sciences, Brunel University London, UK. All the information derived from other works has been properly referenced and acknowledged.

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List of Abbreviation

AHCPN	**A**d **H**oc **C**ognitive **P**acket **N**etworks
ACKs	**A**cknowledgement **P**ackets
AC	**A**dmission **C**ontrol
AODV	**A**d Hoc **O**n-demand **D**istance **V**ector
AoA	**A**ngle **o**f **A**rrival
BRP	**B**ordercast **R**esolution **P**rotocol
CPNs	**C**ognitive **P**acket **N**etworks
CM	**C**ognitive **M**ap
CPs	**C**ognitive **P**ackets
COMPOW	Common Power
CRE	**C**ognitive **R**outing **E**ngine
CLUSTERPOW	**CLUSTER-POWER** protocol
CBTC	**C**one-**B**ased **T**opology **C**ontrol
DPL	**D**istributed **P**ower **L**evel
DPs	**D**umb **P**ackets
DPRR	**D**umb **P**acket **R**oute **R**epository
DACK	**D**umb **A**cknowledgement
DSDV	**D**estination-**S**equenced **D**istance-**V**ector
DISPOW	**D**istributed **P**ower management algorithm
DSR	**D**ynamic **S**ource **R**outing Protocol
DoS	**D**enial **of** **S**ervice attack

EARP	**E**nergy **A**ware **R**outing **P**rotocol
FIFO	**F**irst-**I**n, **F**irst-**O**ut
GAs	**G**enetic **A**lgorithms
HLPCA	**H**ybrid **L**ink **P**ower **C**ontrol **A**lgorithms
IP	**I**nternet **P**rotocol
IntServ	**I**ntegrated Services
IARP	**I**ntrazone **R**outing **P**rotocol
LINT	**L**ocal **I**nformation **N**o **T**opology
LTRT	**L**ocal **T**ree-based **R**eliable **T**opology
LILT	**L**ocal **I**nformation **L**ink-State **T**opology
LETPOW	**L**ink **E**xpiration **T**ime Aware Distributed **P**ower management algorithm
LMST	**L**ocal **M**inimum **S**panning **T**ree
LOADPOW	**L**oad **P**ower **C**ontrol Algorithm
LSP	**L**abel **S**witching **P**ath
LER	**L**abel **E**dge **R**outer
LSRs	**L**abel **S**witching **R**outers
MANETs	**M**obile **A**d hoc **N**etworks
MAC	**M**edium **A**ccess **L**ayer
MB	**M**ail **B**ox
MISO	**M**ultiple-**I**nput **S**ignal-**O**utput
MIMO	**M**ultiple-**I**nput **M**ultiple-**O**utput
MMBCR	**M**in-**M**ax **B**attery **C**ost **R**outing algorithm
MIA	**M**inimum **I**nterference **A**lgorithm
MPLS	**M**ultiprotocol **L**abel **S**witching
MIA	**M**inimum **I**nterference **A**lgorithm
MST	**M**inimal **S**panning **T**ree
NPDUs	**N**etwork **P**rotocol **D**ata **U**nits
OSPF	**O**pen **S**hortest **P**ath **F**irst routing protocol

P2P	**P**eer **t**o **P**eer
PAMAS	**P**ower **A**ware**M**ulti-**A**ccess protocol
PSR	**P**ower-aware **S**ource **R**outing
PAAOMDV	**P**ower **A**ware **A**d-hoc **O**n-Demand **M**ultipath **D**istance **V**ector
QoS	**Q**uality **o**f **S**ervice
QNRD	**Q**oS based **N**eighbor **R**outer **D**iscovery method
RNN	**R**andom **N**eural **N**etwork
RL	**R**einforcement **L**earning
RREQ	**R**oute **R**equest
RREP	**R**oute **R**eply
RTIP	**R**eal-**T**ime services over **IP**
RSSI	**R**eceived **S**ignal **S**trength **I**ndication
RSVP	**R**esource **R**eservation **P**rotocol
READ	**R**esidual **E**nergy **A**ware **D**ynamic
RNG	**R**elative **N**eighbourhood **G**raph
SPs	**S**mart **P**ackets
SINR	**S**ignal-to-**I**nterference-**N**oise **R**atio
SPF	**S**ocial **P**otential **F**ields
SPP	**S**mart **P**acket **P**rocessor
SR	**S**ensible **R**outing
SIMO	**S**ingle-**I**nput **M**ultiple **O**utput
SDN	**S**oftware **D**efined **N**etwork
SAN	**S**elf-**A**ware **N**etwork
SWITCHlan	**S**wiss Education and Research Network
TE	**T**raffic **E**ngineering
TRT	**T**ree-based **R**eliable **T**opology
TCP	**T**ransmission **C**ontrol **P**rotocol
TDOA	**T**ime **D**ifference **o**f **A**rrival
ZRP	**Z**one-**R**outing **P**rotocol

Chapter 1

INTRODUCTION

1.1 Background

Mobile Ad-hoc wireless Networks (MANETs) can be explained as self-organised multi-hope, infrastructure-less wireless networks, which link together a minimum of two stations at one time when there is a lack of access point or central point. MANETs facilitate peer-to-peer (P2P) connections from one device to the next, which function in an ad-hoc approach and are recognised as being within the wireless rang. They be able to linked to a fixed or cellular network, and can form stand-alone groups. In a mobile ad-hoc network, nodes are able to move around and can arrange themselves randomly and as required. All of the users are similarly able to move and change direction during communication. Such networks are recognised as appropriate for and well-aligned to application in those situations where there is the lack of availability of infrastructure or otherwise when the costs associated with one are significant. Such networking is recognised as an architecture comprising a number of different layers, which commonly involve a MAC, which is a physical Medium Access Layer, in addition to transport and network layers.

In ad-hoc networks, nodes arrange themselves, and function in line with identifying neighbours, and organising and reorganising topology. All of the nodes seek out neighbours' activities and accordingly exchange topology data on a periodic basis. Furthermore, ad-hoc networks have the capacity to self-heal and self-configure, and are further acknowledged as scalable. In ad-hoc networks, the hybrid design has the capacity to enhance scalability through bringing together a number of different milt-hop base and relaying stations [1]. Throughout the course of this thesis, power control algorithm use in mobile ad-hoc networks notably the key objective underpinning the power control algorithm is centred on satisfying connectivity whilst at the same time maintaining the power of nodes. Owing to the lack of a centralised controller node with the aim of administering power management, network topology and energy efficiency management present significant challenges, particularly in the case of larger networks recognised as encompassing a number of different nodes. In this vein, the different methods of power control are able to achieve extensive improvements in wireless ad-hoc networks in terms of their lifetime and overall capacity.

1.2 The Ad-hoc Routing Problems

As a result of a number of different factors, as detailed below, problematic environments for routing algorithms are recognised as a result of MANETs. These require consideration can be listed as [2]:

1. The highly dynamic nature of network topology: nodes are able to freely move and travel in any direction and at any speed, and have the capacity to remove or establish connections with other nodes whenever they move. Accordingly, routing information encompassed within the node, such as that pertaining to neighbours, become out-of-date after any topological modification. Ad-hoc network dynamically mean wired routing algorithms are incompetent and useless, which are known to depend on a relatively unchanging network topology.

2. It is common for mobile nodes' resources to be restricted: overall, there is a tendency for mobile nodes to be small, which mean there are limitations in terms of the resources able to be carried. More specifically, battery technology, for example, falls behind in terms of storage and computational technology, which present significant limitations in regards mobile nodes' independence.

3. High packet loss ratios in systems: when contrasted alongside wired systems, wireless communications are recognised as encompassing additional errors as a result of their contention effects and propagation mechanisms. In this vein, fading, multi-path effects, noise, obstacles and reflections are recognised as affecting wireless transmissions. Moreover, significant power

level losses impact signals in line with distance, which increases error probability as a result of node separation. In contrast, node issues and additional technical problems that may be problematic to remove in the case of large moving networks may be recognised as a result of shared wireless access channels. Furthermore, significant degradations in performance in regards upper layer protocols, specifically to TCP, may be generated as a result of high error ratios.

4. The energy efficient routing and optimization in MANETs needs to address the negotiations based scheme without negotiating either the energy or other related parameters such as distance, delays and rate of information. Hence the techniques must be designed focusing on reducing the compromises aiding the increased network populations[3].

1.3 Overview of the Cognitive Packet Network

When defining CPNs (Cognitive Packet Networks), these can recognised as a routing protocol that utilise adaptive methods in line with online measurements with the aim of presenting users with QoS [4–6]. The users are positioned to outline their own goals in terms of Quality of Service (QoS), whether these pertain to maximum bandwidth, minimum delay, minimum power consumption, minimum packet loss, or a combination of such. Importantly, the design of CPN has been carried out in mind of achieving self-improvement through distributed means, notably by taking experience and applying lessons from the network packets, as well as through continuously seeking out the best routes.

In particular, three packet types are utilised by CPN, namely Smart Packets (SPs) centred on discovery, source routed Dumb Packets (DPs) for the purpose of carrying the payload, and Acknowledgement (ACK) packets, which communicate discovered information through either DPs or SPs. Importantly, such informations is utilised across all of the nodes in mind of train the RNNs (Random Neural Networks)[7] and to facilitate decisions in regards routing. Across all nodes in the networks, there is the routing of SPs in line with the measured experiences of prior packets with the same QoS goals and destination. When it comes to investigating all potential routes and rationalising any sudden changes in the network, SPs could opt for a random route, rather than one determined through the RNN, albeit with a small probability (commonly seen to be in the range of 5–10%) [7].

CPN packet headers have undergone change so as to facilitate the gathering of network information by packets, notably in line with the QoS goals outlines. Accordingly, when the packets pass along the network, QoS informations are stored, whether (counters or timestamps, etc.) for example, with a specialised data storage area of the packet header assigned to this role, referred to as a Cognitive Map (CM) [8]. Importantly, upon the arrival of the packet at its destination, there is the generation of an ACK packet; this stores data pertaining to the route adopted by the original packet, as well as the measurement collected throughout the course of the journey. Subsequently, the reverse route is then followed by the ACK. Whenever the ACK visits a hope, information is then deposited and stored in a short-term memory bank referred to as a Mail box (MB). Upon reaching the source, the route to be adopted by the DP will then be established by the ACK.

Across all of the nodes, a particular RNN (Random Neural Network) which is recognised as encompassing a number of different neurons as potential outgoing links gives the SP the decision as to the route, which is done as an output link; this is aligned with the most excited neuron, and owing to the fact that a unique solution is presented by the RNN for any input variables or weights, the choice is similarly unique. Reinforcement learning (RL) is the learning method applied with RNN; this utilises a decision's recognised outcome in order to present the routing decision with either a punishment or reward, meaning subsequent decisions will either maintain or enhance the required QoS goal.

In the case of ad-hoc CPN (AHCPN), a path is quantified by path availability through the overall likelihood of identifying the links and nodes available for routine. This is recognised as a function of battery lifetime at nodes, as well as communication channels' signal–noise ratio. Accordingly, any low-power nodes have the ability to lengthen their working lifetime, with routes chosen in line with power considerations, subsequently resulting in the creation of stronger communication paths.

1.4 Motivations

In ad-hoc networks, the most commonly utilised MAC layer is that of IEEE 802.11 standard, which utilises fixed transmission power for communication. Fixed standard, which is known to utilise fixed transmission in such networks, imposes significant negative effects on performance in the case of congestion; however, network performance could be improved through Transmission Control Power initiative. Nonetheless, it remains that power improvement in the network cannot be achieved through stand-alone power control; this work provides a solution in regards QoS in ad-hoc networks. Notably, the suggestion is made as to an intelligent, adaptive power control tool through which network characteristics and performance are critical to power control. When considering AHCPN in line with a number of different uses, it has been found to be effective; such uses might include power-based routing in mobile ad hoc networks, traffic balancing, denial of service (DoS) protection, and admission control (AC).

1.5 Research Aim & Objectives

Accordingly, there is the aim to provide a framework centred on achieving efficiency across ad-hoc cognitive packet networks, with the assurance of connectivity alongside a framework where QoS, both required and attained, oversees transmission power.

The objective of the research is:

- Presenting a full advantages to Transmission Control Power algorithms, with QoS end-to-end got little attention.
- Power control solutions that have been adopted thus far have been inadequate in terms of providing adaptive QoS-aware solutions to power control; this suggests that such approaches are unable to make use of network resources.

1.6 Contributions

There are three main contributions of this thesis which are summarised in the following:

1. AHCPNs with adaptive Distributed Power management algorithm (DISPOW) power control scheme have been presented, which aim at lessening the utilisation of power across nodes. Importantly, the enhancement of nodes was achieved through transmission power decreases, thus meaning that the energy availability of the nodes does not significantly decrease. The end result highlights the flow of packets through the network at a level of power recognised as appropriate and suitable in regards identifying and determining communication without inducing any form of disruption across neighbouring nodes. In addition, the packets will opt for flow through nodes seen to have a greater battery life and with a greater chance when contrasted alongside those nodes presenting shower life.

2. Contribution two, divided into two parts , the first part is enhanced DISPOW algorithm which is a new power control algorithm for Mobile Ad-hoc Network (MANET) has been presented in this work, with the algorithm presented a Link Expiration Time Aware Distributed Power management algorithm, namely LETPOW. The key aim underpinning this is the periodic checking of Transmission power, Connectivity, Routing overhead, Interference level and Node mobility in MANET. A modified time-varying signal-to-interference-noise ratio (SINR) formula is devised and presented, with the suggested algorithm taking into account a variety of different elements, namely continuous time interval, link expiration time, and the number of scheduled slots when contrasted alongside the present Distributed Power management algorithm (DISPOW) when it comes to power distribution.

   The second part is AHCPNs with DISPOW and Link Expiration time Aware Distributed Power management algorithm(LETPOW) power control scheme have been presented, which have undergone comparison with the study method of Lent et al.[9], which notably aims at lessening the utilisation of power across the nodes. Importantly, the nodes were improved through ensuring transmission power was decreased, thus meaning that the availability of node energy would not significantly decrease. The ultimate outcome shows LETPOW and DISPOW as demonstrating sound performance. In the chapter 4, a new power control algorithm, namely

LETPOW, has been presented, which is seen to place emphasis on Link Expiration Time. The key objective in this regard is to complete periodic checks in relation to Connectivity, Interference level, Transmission power, Node mobility and Routing overhead in AHCPN. Importantly, this particular algorithm improves overall system performance and further enhances path length and packet loss ratio overall. Our main aim is to periodically check Connectivity, Transmission power, Interference level, Routing overhead and Node Mobility in AHCPN. The LETPOW algorithm noticeably enhances the performance of the system and improves average packet loss ratio and path lengths.

3. AHCPNs with DISPOW,LETPOW and HLPCA power control scheme have been presented, which have undergone comparison with the study method of Lent et al. [9], This Contribution has detailed the way in which power can be assigned in single and multi-hop wireless networks, with consideration towards network load, Transmission Power, Received Signal Strength Indication, connectivity, Link expiration time Power level and Path loss model in design cross-layer power control applied for transmitting information across the various intermediate layers.

1.7 Thesis Outline

The work in this thesis is organized into six chapters. Each chapter will start with a brief introduction providing an overview and highlighting the main contributions of the chapter. At the end of each chapter a brief Summary is presented.

Chapter 2 starts with explaining the Cognitive Packet Networks (CPN) and Ad Hoc Cognitive Packet Networks (AHCPNs) algorithms and the technique they learn how to succeed their routing goals. RL (Reinforcement learning) and RNN (random neural networks) are discussed as one of many ways to achieve learning; also, introducing some basic concepts which will be used in the later chapters. Later,it provides Literature review

Chapter 3 discusses, the Distributed Power management algorithm (DISPOW) was applied in order to implement an adaptive power control scheme, devised as a network-assisted functionality of AHCPN (ad hoc cognitive packet) based routing. where adaptive transmission power control influences network performance has been demonstrated, such as in regards to throughput, packet loss, delay and energy.

Chapter 4 presents update DISPOW algorithm, The suggested algorithm is a Link Expiration Time Aware Distributed Power management algorithm,(LETPOW) which focus on Link Expiration Time. Our main aim is to periodically check Connectivity, Transmission power, Interference level, Routing overhead and Node Mobility. A modified time-varying signal-to-interference-noise ratio (SINR) formula was deliver . The proposed algorithm considers additional parameters such as link expiration time, continuous time interval and the total number of scheduled slots compared to the existing Distributed Power management algorithm (DISPOW) in distributing the power.. Furthermore, we apply AHCPNs with LETPOW power control scheme, devised as a network-assisted functionality of AHCPN (ad hoc cognitive packet) based routing. where adaptive transmission power control influences network performance has been demonstrated, such as in regards to throughput, packet loss, delay and energy.

Chapter 5 The algorithm of power control transmission, assignment results in a greater degree of efficiency in the network through the application of hybrid power control algorithms, namely HLPCA which is Link Expiration Time Aware Distributed Power management algorithm, (LETPOW) and Load Power Control Algorithm (LOADPOW), deal with cross-layer power control applied for transmitting information across the various intermediate layers, which is seen to place emphasis on the concept of Transmission Power, in addition to RSSI (Received Signal Strength Indication), and Suitable distance between the receiver and the sender is calculated in the network by Euclidean distance. Furthermore, connectivity, Link expiration time, Power level. In this vein, the difference between the received power and transmission power for the amount of mobile nodes present within the hybrid power control algorithms,(HLPCA) network can be calculated with the use of the path loss model.

Finally Chapter 6 introduces the study findings and conclusions, in addition to suggestions for future work.

Chapter 2

BACKGROUND AND LITERATURE REVIEW

2.1 Mobile Ad Hoc Networks and Routing Protocols

2.1.1 Mobile ad hoc networks

The term ‘ad hoc’ may be defined as ‘taking different forms’, and ‘may be recognised as being networked, mobile or stand-alone’ [10]. In essence, ad hoc suggests that the formation of the network has been carried out in a spontaneous way in an effort to satisfy particular objectives and fulfil immediate demand.

Wireless transmissions development and the popularity of portable computing devices have facilitated communication anywhere and at any time. There is now the ability of users to move around whilst remaining linked to the world. This may be referred to as mobile computing or nomadic computing; this has been the focus of much attention during more recent times [11–14]. Overall, the majority of mobile computing applications used in the modern-day world require single hop connectivity to the wired networks. This is the most common cellular network framework facilitating the requirements of wireless communications through the installation of access points of base stations. In such cases, communication between two mobile hosts is dependent on the fixed base stations and the wired backbone.

Importantly, however, the wired backbone infrastructure might not be available to mobile hosts for use; this could be owing to a number of different factors, including radio shadows and natural disasters, for example. Furthermore, it might not be practical to create adequate fixed access points as a result of cost and performance elements: for instance, it is common for fixed network infrastructure to be prohibited in festival grounds, outdoor assemblies, wilderness areas and outdoor activities. Furthermore, when there are emergency military manoeuvres or search-and-rescue events, a temporary communication network needs to be implemented as quickly as possible.

When any of the above situations arises, a more practical and permitted option may be a mobile ad hoc network (MANET) [15]. A MANET may be recognised as encompassing a number of different mobile hosts, all functioning without the assistance of the established infrastructure of centralised administration (such as access points or base stations, for example). Communication may be facilitated through wireless links amongst mobile hosts via their antennas. As a result of various considerations, including channel utilisation and radio power limitation, for example, it might not be possible for a mobile host to communicate directly with other hosts in a single hop manner. In such an instance, there is the occurrence of a multi-hop scenario, which involves the packets being sent by the source host, which then are relayed by a number of different intermediate hosts before reaching the destination host. Accordingly, in a MANET, all of the mobile hosts need to act as a router.

2.2 Cognitive Packet Network

The author Erol Gelenbe et al. [16], introduce Packet-switching networks are where intelligence is constructed into packets, as opposed to in the protocols or at the nodes. Networks encompassing such packets are referred to as Cognitive Packet Networks. In CPNs, Cognitive Packets route themselves to avoid congestion and to avoid being lost or destroyed. Cognitive packets experience learning in line with their own observations as they travel the network, as well as through other packets' experiences. Minimal dependence is invested into routers, with each cognitive packet demonstrating progressive refinement in regards its own framework in the network as it travels, with the model utilised in the making of routing decisions. In the most significant of instances, a cognitive packet will be aware of its position in the network without needing to request the switch identity of where it is being stored;

this means that packets demonstrate self-routing without needing to depend on the algorithms of the routes as provided by the nodes in the network. Cognitive packets demonstrate minimal reliance on routes, meaning that nodes within a network act in the role of buffers, processors and mailboxes.

When considering telecommunication systems, learning algorithms and corresponding adaptations have been highlighted by a number of professionals and academics in the past[17, 18]. Nonetheless, such concepts have not been directly implemented in the networks owing to the lack of models facilitating decentralised communications control. Notably, CPs store information in their own Cognitive Map (CM) and make changes and updates to the CM, with their routing decisions made using the code included in each packet. This code encompasses neural networks or other adaptive algorithms, which will be considered in greater depth below. Figure 2.1 provides an overview of a Cognitive Packet's contents. The CM at a node is updated by the processor of the node, as can be seen in Figure 2.2. In a CPN, nodes are utilised by the packets as 'parking' or resting areas; this is where decisions are made and they then route themselves.

Fig. 2.1 Cognative Packet Representation.[16]

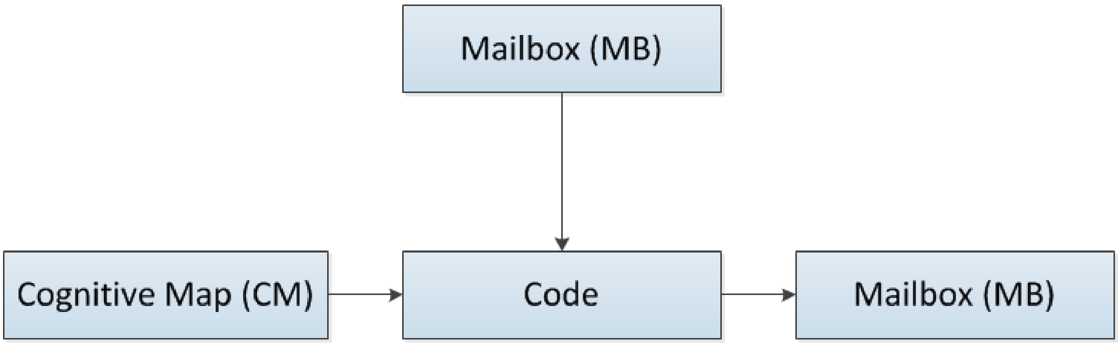


Fig. 2.2 A Cognative Packet Update by a Node CPN.[16]

Furthermore, nodes are also utilised as locations where they may read their mailboxes. The node might fill up a mailbox, and other packets passing through the node might do the same. Furthermore, packets might also use nodes in the role of processor, thus enabling their code to be executed so as to update their CM, with their routing decisions subsequently executed. Owing to code execution, specific information may be moved to certain mailboxes from CP. The nodes might execute the CPs' codes in line with their priorities between CP classes, such as in the case of a function of QoS requirements, which may be included within the identification field. A potential routing decision could be simply centred on maintaining the same node position until there has been a change in network circumstances. Nonetheless, overall, routing decisions seem to stem from the CP being positioned in some output queue, in a priorities-based order, as established by the CP code execution[16]. A CPN node and a CPN can be seen in the schematic overview presented in the following two Figures 2.3 and 2.4.

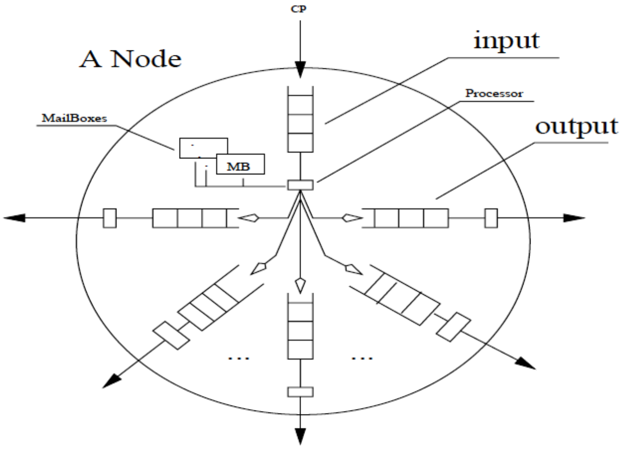


Fig. 2.3 A CPN Node Schematic Overview.[16]

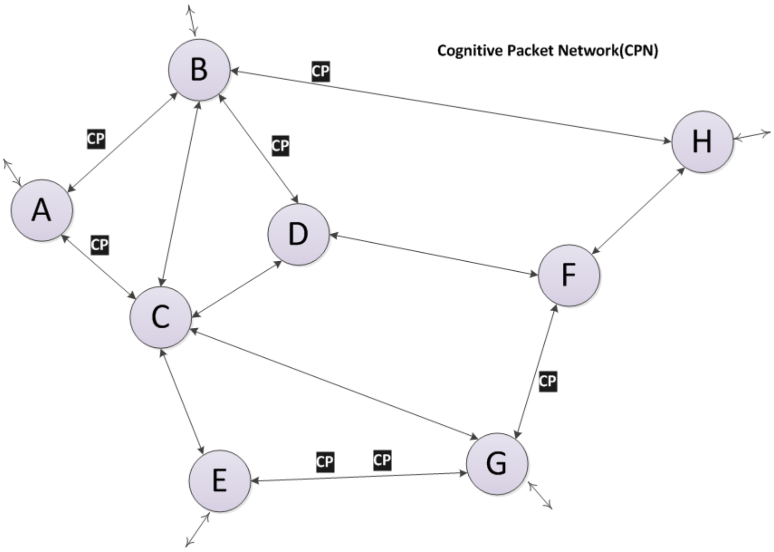


Fig. 2.4 A CPN Schematic Overview.[16]

CPs are categorised in line with CP class, where classes are seen to contain comparable features, such as quality of service (QoS) requirements , sets of internal states, control rules, and input and output signals, for example. Such signals are recognised information units, which are utilised by CPs when communicating with one another via mailboxes in the nodes. Such signals also may be seen to emanate from the environment (*nodes, existing end-to-end protocols*) towards the CPs. A number of different fields are contained within the Cognitive Packets, as follows:

1. The Identifier Field (IF): This delivers individual CP identifiers, in addition to information pertaining to the class of packet to which it may belong, including its Quality of Service (QoS) criteria.

2. The Data Field: Comprising the ordinary data that it is transporting.

3. A Cognitive Map (CM): Seen to encompass the more common Source and Destination (S-D) information, in addition to a map detailing where the packet considers it to be "thinks", the packet's view of the network state, and the information pertaining to its chosen destination. Subsequent S-D data may also be stored in the Identifier Field.

4. Executable Code: This is utilised by the CP when updating the CM. This code encompasses learning algorithms aimed at CM updates, as well as algorithm decisions that utilise the CM.

A CPN node acts as a CP and mailbox storage area, and can be used to exchange data between and amongst CPs, as well as CPs and the node. When CPs arrive from the input links, there is an input buffer, a number of mailboxes and a set of output buffers, all of which may be related to output links. A CPN's nodes include the following functions:

1. Packets are received by the node through a finite group of ports, with these then stored into an input buffer.
2. Packets are transmitted to other nodes through a group of output buffers. When there is the placement of a CP in an output buffer, it then is transmitted to another destination node; this outlines the priorities indicated in the output buffer.
3. A node receives the information by the CP, which is stored in a mailbox. The mailbox may be held for particular CP classes or otherwise may be specialised by CP classes. As an example, there may be different mailboxes for packets, as established by different Source–Destination pairs.
4. The code for each CP is executed by the node in the input buffer. Throughout the CP code execution process, the CP might request that the node's identity be declined, with information pertaining to its local connectivity ("i.e. This is Node A, and I am connected to Nodes B, C, D via output buffers") provided whilst executing its code. "In some instances, the CP might already hold such data in its CM owing to the initial data it received as its source, and also owing to its own memory of the moves sequence demonstrated. Owing to such an execution":

- The packets' CMs in the input buffer undergo an update,
- Particular information is moved from CPs to particular mailboxes, and
- A CP that has chosen to move to an output buffer is then transferred to this location, encompassing the requested priority.

2.3 CPN Packet Format

Packets in CPN are of variable size. They contain three general sections: a header, a cognitive map (CM) and an area for payload. table 2.1 illustrates the format of the CPN packets [2].

Table 2.1 **CPN Packet type field.**

Type field	Use
0	dumb packet
1	smart packet
2	acknowledgment packet

1. Type (4 bits)—identifies the packet type (see above table 2.1).

2. Proto (4 bits)—indicates the transport-layer protocol for the packet. This field remains optional in this study.

3. Header length (8 bits)—indicates, in words of 32 bits, the length of the packet header plus the length of the cognitive map.

4. Total length (16 bits)—indicates the length of the packet in bytes, giving a maximum possible packet size of 65,535 bytes. However, the real maximum size is limited by the underlying network technology.

5. Source address and destination address (32 bits)—are 32 bits long, making a total address space of 4,294,967,296 hosts.

6. Source port number and destination port number (32 bits)—identify the sockets of the connection for the packet.

7. Cognitive Map (variable)—records information of the nodes on a path. Each entry contains two fields: the node's address and the arrival time.

8. Payload (variable)—transports user data or higher level protocols, such as TCP and UDP.

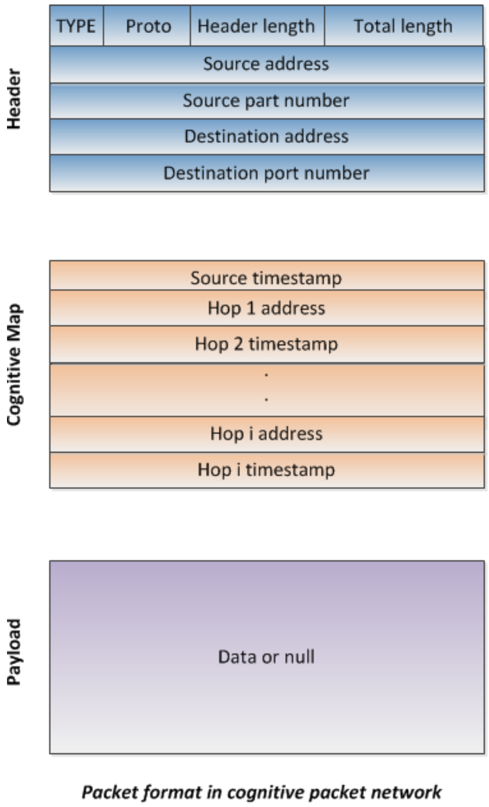


Fig. 2.5 Packet format in CPN [2].

2.4 The Operation of CPN

CPN may be defined as an adaptive packet-routing protocol encompassing sophisticated monitoring and capabilities geared towards self-improvement in addressing QoS through the application of adaptive methods adhering to on-line measurements [4, 5, 19–21] . It is acknowledged as a distributive protocol through which users are able to outline their particular criteria in regards QoS, i.e. QoS goals; these might include maximum bandwidth consumption, minimum delay or minimum costs, etc, for example. Essentially, CPN is designed in mind of achieving self-improvement through learning experience of smart packets (SPs).

CPN utilises three different packet types, namely SPs, otherwise referred to as cognitive packets, which are concerned with information discovery, source-routed dumb packets (DPs), which are charged with carrying the payload, and acknowledgement (ACK) packets, which bring back information that has been identified by SPs and that are used in nodes for the purpose of training neural networks. Importantly, a user is responsible for generating SPs, with the user seeking to establish a pathway to a particular CPN node or otherwise with the aim of identifying network state parts, such as mobile or fixed nodes, location, topology, power levels at nodes, paths or QoS metrics, for example. Essentially, the role of the SP is focused on the exploration of the network and the identification of the most efficient QoS routes for all source – destination pairs in the network; the users assign the goals that govern how the SPs behaves. At each hop, the routine of the SPs is determined in line with previous packets' experiences, following the same goals with the same destination. SP decisions are made in line with a learning algorithm. Accordingly, so as to ensure all potential routes are examined, at some hops, a random routing decision is made by each of the SPs, with a small probability (usually 5%) utilised. In order to avoid overburdening the system through lost packets or unsuccessful requests is circumvented, a lifetime constraint is applied to all packets, with the restriction made in relation to the number of nodes visited. In this regard, rather than referring to these as QoS specifications, the term 'goal' is used so as to highlight the lack of QoS guarantees, and also that the CPN offers what may be recognised as only a best effort service[22]. In effect, the goal is a QoS criterion stipulating that the SP directs its efforts towards achieving what has been outlined, i.e. maximum pathway security level, minimum delay, maximum bandwidth, minimum packet loss, minimum variance of packet delay, minimum power consumption in wireless node use, etc.

When considering the routers in the CPN, restricted functionality can be seen. Node tasks might encompass receiving packets from a number of different ports, storing such packets in an input buffer, and transmitting packets to other nodes through output buffers, notably in line with the priority of the discipline. Furthermore, information received from SPs is stored by routers in short-term memory stores, which are labelled as mailboxes (MBs), as detailed in [4, 5]. There might be more than one MB in a node as each one might be utilised by a particular class of SPs with common characteristics, such as destination or QoS goal, for example. Importantly, MBs are read by SPs, with the information stored within utilised in an effort to execute the code through the node, make changes to and update MBs in the node, and accordingly make decisions in terms of the subsequent hop movement. Furthermore, the role of discarding packets that may have exceeded the permitted 'time out' value is also assigned to routers.

A CPN's individual DPs or SPs all detail the usual fields included in TCP/IP packets, in addition to various other fields offering the code required in order to interact with visited nodes [5, 21]. Examples of such information include computing the goal, reading the MB, making subsequent hop decisions, and running the adaptive learning algorithm. SPs use learning algorithms that undergo further examination and discussion. Notably, an SP stores details of any route it follows, and further documents the time (keep timestamp)at which nodes have been visited. Upon arriving at its outlined destination, there is the creation of an ACK packet, with the information the SP collected in regards measurement and routing then transferred to the ACK. Importantly, the reverse pathway back to the source will be followed by the ACK packet, notably of that followed by the corresponding SP; notably, in order to ensure circuits are avoided, a loop-removal algorithm is utilised. It should be recognised that the reverse pathway adopted is not necessarily the shortest one achieving the most efficient goal satisfaction. As the route is followed by the ACK, QoS information is deposited in the visited nodes' MBs. Furthermore, at the source, the route adopted by an ACK, in addition to its QoS data, is cached in a table, referred to as the dumb packet route repository (DPRR).

In the DPRR, the final path inserted is that to be followed by the DPs; the DPs are those packets afforded with the task of carrying the payload of a specific connection. Owing to the fact that he path-identification approach is ongoing, DPs choose the most recently identified, most efficient route, spanning source to destination, which is a result of the SPs from the same QoS categorisation previously recognised in the network. Moreover, time-related information are also gathered by the DPs throughout their trip across the network, which then is taken back to a source node by a dumb acknowledgement (DACK) packet. At this point, the MBs of the traversed nodes may be updated. CPN has been recognised as able to function within mobile ad-hoc conditions [23]. In this vein, ad-hoc CPN, referred to as AHCPN limits the adoption of flooding, making use of this only as a final option, and instead uses unicast in the place of broadcasts as much as is possible. Through implementing the CPN algorithm, it is possible for unicast routing decisions to be adapted in line with exploiting resource use in mobile ad-hoc networks, thus decreasing the chances of node unavailability through power shortages, whilst also increasing quality of service (QoS).

2.5 Internal Data Structures of Ad-hoc Cognitive Packet Networks

This section provides an in-depth explanation of the (AHCPN) protocol. Such packets are structured across three key domains, namely header, cognitive map and payload. Payload is carried out in the case of DPs. Figure 2.6 provides an illustration as to the format of such packets [2]:

1. Type (4 bits), which identifies the type of the packet: 0=dumb packet, 1=smart packet, 2 and 3=acknowledgements stemming from dumb and cognitive packets, respectively.
2. QoS (4 bits), which identifies the quality of service for the packet, as deemed necessary. The quality of service aim establishes the reinforcement learning tool to be implemented in order to update the random neural network in the CPN algorithm.
3. Header and cognitive map length, in words, spanning 32 bits.
4. Cognitive map cursor: suggests the position of the node on the cognitive map when transmitting the node.
5. Packet identification (32 bits): provides a unique differentiation of the packet. ACKs carry the same packet identification as their originating dumb or smart packets. The identified is applied at the source node in order to eradicate packets waiting for retransmission, following the arrival of the associated acknowledgement. Moreover, smart packets provide a copy of their packet identification; this is found in the nodes and identifies nodes that have been visited before.
6. Destination address (32 bits): implementing an IPv4 addressing space.
7. Cognitive map (variable): an arena in which packets store data pertaining to the network. A cognitive map within an AHCPN comprises the following data:
    (a) Source and Intermediate Hop Addresses: Implements IPv4 address format. All nodes visited are assigned a new record by smart packets. In contrast, dumb and ACK packets carry the cognitive map provided at the source node,
    (b) Timestamp fields: These detail the arrival time at any intermediate node. The entry corresponding to the source node provides insight into the departure time of the packet.

   (c) Path availability data field: Communicates the change of identifying all nodes and links available for routing from the present location through to the destination.

8. Payload: The area for transporting IP datagrams.

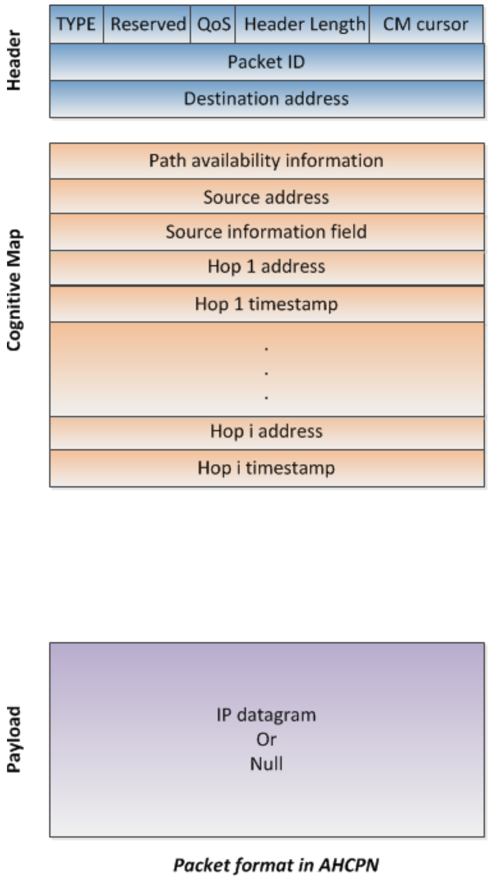


Fig. 2.6 Packet format in AHCPN [2].

2.6 Ad-hoc Cognitive Packet Networks

A routing algorithm's overall efficiency essentially rests on the network state information's accuracy and what is accessible when making decisions. Ensuring the network state's information is maintained and up-to-date can affect network resource consumption, with a number of different mobile ad-hoc routing proposals making use of flooding or network-wide updates that mean the network is used for a long period of time. Importantly, a number of different ad-hoc network (MANETs) routing proposals have shown dependency on broadcasts flooding networks and identifying paths. Essentially, this facilitates nodes in identifying the quickest path, although these are not usually expected to be linked with QoS [6].

One of the key benefits to be derived from AHCPNs over such routing algorithms is that network state collection places emphasis on active paths as opposed to network-wide collection, thus meaning that the algorithm is able to make decisions with the information at its disposal[5, 24–27]. As the algorithm becomes better informed and has access to more information, the decisions made are more focused, meaning routes demonstrate greater efficiency in terms of QoS. Importantly, to a minor degree, broadcasts are used in order to manage unexpected network dynamics. QoS differentiation is provided by the algorithm so as to achieve best effort traffic without involving complexity in defining a resource reservation mechanism in the network. Notably, source nodes send out control packets that are governed with identifying routes on-demand; these are referred to as smart packets. The routes identified then are utilised by dumb packet flows with the aim of transporting user data through source routing. Moreover, smart packets are also sent as a small percentage of the dumb packets sending rate; these have the aim of achieving enhancements across network resource use and path performance [23]. For all of the flowers, a random neural network (RNN) [27–30] is created by the smart packets at all individual hopes, encompassing as many neighbouring neurons as possible along the pathway. When in a steady state, the neighbour found to be linked with the most excited artificial neuron establishes the unicast decision for the packet. RNN training is focused on network status observations made by packets. Packets are recognised as gathering information of the status of networks as they traverse the network towards their destination. Once they have done this, the network status observed by the packet is then distributed to the nodes across the path, notably in a reverse direction. A number of metrics, such as path availability, gathering information in reverse is seen to be more efficient; in such an instance, acknowledgements both gather and distribute network status when in movement.

MANET applications typically require low-latency paths for packets, whilst maintaining effective use of network resources. In an effort to accomplish this objective, both path availability and timing information should be gathered and accessible to smart packets. The cognitive map is a domain inside the packet with the purpose of storing network status observations. Timing information may be garnered by gathering arrival times at nodes, with this information then utilised in order to calculate and determine the round-trip latency from a particular node to the destination. Nodes' residual energy may be incorporated within the path availability pathway so as to facilitate smart packets making energy-aware decisions. Acknowledgements that are travelling to the source node, utilising the reverse path, establish a feedback system that provides ongoing communication to nodes relating to the present performance of routing decisions. This information is kept in the nodes' RNNs, which can be accessed in the future smart packet so as to facilitate reinforcement learning. In this regard, AHCPN uses this method of learning to facilitate behavioural learning amongst RNNs without the need to provide explicit definitions concerning the desired input–output pairs. Following the identification of a routing decision; the performance demonstrated through this decision is then communicated to the router. In line with this information, the weights of the RNN may increase or decrease, with the last decision rewarded or punished, respectively.

The process follows a particular order: the flow is characterised in line with a provided QoS goal, G, which then is created in regards the number of network metrics of interest. In such an instance, the G then is formulated a function combining round-trip delay and residual energy information. It may be assumed that a packets sequence adheres to path $P = (n_1, n_2, ..., n_h, ..., n_d)$. Moreover, upon finding a hop $n_h (1 < h < d-1)$,the performance reward, as observed by the p_{th} th packet in the sequence, may be recognized as the inverse of the goal $R_p(n_h) = G_p(n_h)^{-1}$. Subsequently, the expected performance and reward are compared in an effort to establish the reinforcement to be applied. The expected performance is then estimated through the exponential average $T_p(n_h) = \alpha T_{p-1}(h_i) + (1-\alpha) R_p(n_h)$, where α is a constant $0 < \alpha < 1$. For the QoS q at node nh, the RNN weights undergo adjustment as detailed below, assuming that the earlier decision was the neighbour recognised by k:

- If $T_p(n_h) \leq R_p(n_h)$
  - $w^+(i,k) \leftarrow w^+(i,k) + R_p(n_h)$,
  - $w^-(i,j) \leftarrow w^-(i,j) + \frac{R_p(n_h)}{4}$,$j \neq k$
- Else
  - $w^+(i,j) \leftarrow w^+(i,j) + \frac{R_p(n_h)}{4}$,$j \neq k$

- $w^{-}(i,k) \leftarrow w^{-}(i,k) + R_p(n_h)$,

Accordingly, ***RNN*** weights either decrease or increase as a function of the performance demonstrated. In order to ensure ever-growing goals are circumvented, there is the normalisation of the weights following this step.

2.7 Learning and Decision-Based Algorithms

A number of different algorithms have been utilised in the CPN as decision and learning methods aimed at SPs establishing effective and efficient routes from source to destination, in line with the goals and criteria outlined in each regard.

2.7.1 RNN-based algorithms

The RNN may be recognised as a neural network framework, inspired by biology, and recognised by the presence of both negative and positive, notably inhibition and excitation, respectively, signals, witnessed in the form of unit amplitude spikes flowing from one node to another and in between, whilst also making changes to neurons' potential. All of the neurons notably may be linked to another neuron, with each of the links recognised by an inhibitory or excitatory weight [7]. In its first instance, it was first presented in [28], with subsequent updates made in [28] and further developments witnessed in [29, 31–35]. Despite the fact that the RNN framework initially was motivated by biophysical neural networks, nonetheless, in a number of different domains have benefited from successful application, such as in regards associative memory [36–38], image-processing [39–41], texture-generation [42, 43], video QoS and compression [39, 44–49] in addition to the assignment of tasks [50] and the allocation of resources [51]. Furthermore, the utilisation of negative customers in queuing networks has also inspired in this regard, subsequently leading to G-networks [52–56].

With the exception of CPN, [57] implements RNN-based routing, with RNN applied in an effort to learning minefield characteristics through taking data from various sensors, fusing it, and accordingly navigating autonomous agents, robots and/or vehicles. Importantly, the CPN predecessor was the routing of agents detailed in [7]. In this regard, there is the routing of agents in line with previously outlined goals, which might include both quickly and safely traversing a risk-encompassing metropolitan grid, using the RNN to learn from the experiences of other agents and their own observations. Moreover, the use of the RNN is also recognised in terms of its ability to control agent movement within a simulator's realistic life scene [58]. It is important to note that, in an RNN, the state q_i of the ith neuron, which signifies the overall potential that the ith neuron is excited, fulfils the non-linear equations system detailed below:

$$qi = (\frac{\lambda^+(i)}{r(i)+\lambda^-(i)}) \tag{2.1}$$

where

$$\lambda^+(i) = \sum_j q_j w^+_{ji} + \Lambda_i, \tag{2.2}$$

$$\lambda^-(i) = \sum_j q_j w^+_{ji} + \lambda_i, \tag{2.3}$$

$$r(i) = \sum_j [w^+_{ij} + w^-_{ij}] \tag{2.4}$$

In which w^+_{ji} may be recognised as the rate demonstrated by the neuron j in communicating 'excitation spikes' to neuron i at the point at which j is excited. Furthermore,w^+_{ji} is the rate demonstrated by neuron j in sending 'inhibition spikes' to neuron i at the point at which j is seen to be excited, with *r(i)* the finalised rate showcased by the neuron i. Notably, Λ_i and λ_i may be recognised as rate of the ongoing external positive and negative signal arrival rates, respectively, which are seen to adhere to stationary Poisson distributions. When there is an N neuron identifiable in the network, the network parameters are N by N 'weight matrices', $W^+ = w^+(i,j)$ and $W^- = w^-(i,j)$, which need to be 'learned' from input data.The weights w^+ij and w^-ji, in addition to Λ_i and λ_i, are recognised as identified across all *i,j* instances.

A number of different strategies have been learning in line with the *RNN*. As an example, Hebbian learning underwent early testing in the preliminary *CPN* development phases, and was recognised as lacking in speed and efficiency [22]. Moreover, a number of other algorithms have been put forward, such as feed-forward learning *RNN* with the adoption of a gradient descent quadratic error functionality, in addition to RL. Two examples of such algorithms are detailed in the following section

2.7.1.1 Reinforcement Learning Random Neural Networks

This particular algorithm is recognised as one of the most valuable in CPN implementations. To begin with, the RL algorithm was based on an RL algorithm, encompassing internal expectations for the RNN that was development in mind of maze navigation utilisation [59] . The onset of an SP is responsible for triggering RL algorithm initiation; in other words, and more precisely, each router is known to store a particular RNN for every QoS class instance, as well as for every source – destination pair that is active. Importantly, all of the RNN nodes, which are recognised as the decisions made in selecting an SP's particular output link, comprises a number of different neurons notably, the same number as outgoing links [19]. With this noted, decisions are made by choosing the output link J for which the corresponding neuron is the most excited, *i.e.* $q_i \leq q_j$ for all i = 1, . . . , N, where N is the number of neurons (possible outgoing links). In the case of the network's ith neuron, the state of the q_i is seen to represent the likelihood that the ith neuron is excited, thus inferred as the overall potential of the ith outgoing link to be chosen for the routing of the SP's.

In CPN, the weights to punish or reward a neuron, specifically in line with the degree of goal fulfilment measured in relation to the associated output, is determined and changed by the RL process; in other words, weights to reward or punish are determined in line with whether the SP demonstrated failure or success in achieving its QoS objective. Importantly, for each source–destination pair, each *QoS* class encompasses a QoS Goal G; this details a function requiring minimisation. Goal satisfaction is communicated through a role. When considering a goal G that needs to be minimised by a packet, the reward R then is formulated as follows: R = 1/G . Essentially, the updates to RNN weights are made in line with the following-detailed threshold T:

$$T_k = aT_{k-1} + (1-a)R_{k,} \tag{2.5}$$

where R_k, k = 1, 2, . . ., are successive measured values of reward R and a is a constant (0 < a < 1) applied in an effort to gear the responsiveness of the algorithm: for instance, a = 0.8 may be taken to infer the average five past values of R being taken into account. In line with the difference between the current reward R_k and the last threshold T_{k-1}, neurons are either punished or rewarded. Accordingly, should the value of the reward R_k, which notably refers to corresponds to neuron j

garnered most recently be seen to be greater than the previous value of the threshold T_{k-1}, then there would be a notable increase in the excitatory weights being incorporated within that neuron, with a slight increase (in order to reward for new success) recognised across the inhibitory weights resulting in other neurons. Importantly, should the new reward be found to be no higher than the prior threshold, then there would be a moderate increase witnessed across all excitatory weights resulting in all neurons, except for in the case of the previous winner; further, there would be a significant increase in the inhibitory weights resulting in the previous winning neuron, which would punish it for its lack of success this time. Accordingly, should the firing rate prior to the modification taking place be *ri*, then, for each neutron *i*, it is given as follows:

$$ri = \sum_{m=1}^{n} [w^{+}(i,m) + w^{-}(i,m)]. \tag{2.6}$$

Primarily, T_{k-1} is calculated, with the network weights subsequently undergoing update across all neurons $i \neq j$ as follows:

- If $T_{k-1} \leq R_k$
    - $w^{+}(i,j) \leftarrow w^{+}(i,j) + R_k$,
    - $w^{-}(i,l) \leftarrow w^{-}(i,l) + \frac{R_k}{n\text{-}2}$, if $l \neq j$
- Else
    - $w^{+}(i,l) \leftarrow w^{+}(i,l) + \frac{R_k}{n\text{-}2}$, if $l \neq j$
    - $w^{-}(i,j) \leftarrow w^{-}(i,j) + R_k$,

So as to avoid all large weights are circumvented which essentially would result in numerical problems when implementing algorithms, and also in consideration of the fact that RNN weights' relative size, as opposed to actual values, determine the position of the neural network the weights need to undergo re-normalisation by completing the below-detailed operations. Primarily, for each i r_i^*, the following is calculated:

$$r_i^* = \sum_{m=1}^{n} [w^+(i,m) + w^-(i,m)], \tag{2.7}$$

and then the weight are re-normalized with:

$$w^+(i,j) \leftarrow w^+(i,j) * \frac{ri}{r_i^*}, \tag{2.8}$$

$$w^-(i,j) \leftarrow w^-(i,j) * \frac{ri}{r_i^*}. \tag{2.9}$$

Following the calculation of new values of the weights, the non-linear system of equations (2.1, 2.2,2.3 and2.4) can be solved in an effort to determine the *qi* and accordingly select the most excited; this subsequently will derive at the link to be followed by the *SP*. Such a process undergoes repetition for every *QoS* class, *SP* and source–destination pair

2.8 Integration with IP applications and other protocols

In CPN, all of the most common fields identifiable in the usual TCP/IP packets can be found in SPs and DPs, in addition to various fields detailing the code necessary to interact with nodes upon visiting [21]. Upon discarding such additional data, the smart and DPs then may be considered as everyday TCP/IP packets. Nonetheless, when considering ACKs, these are viewed as particular in regards the CPN model, despite the fact that they, similarly, are derived from TCP/IP packets. Owing to the fact that the routine decisions are taken in line with the code completed by the CPN packets, a CPN network's nodes generally are stored in TCP/IP routers; this means that they may be applied with a far less complicated and expensive software and hardware when contrasted alongside more modern-day TCP/IP routers. Importantly, the CPN acts as a substitute (replacement) for the IP layer owing to the fact it presents an alternative approach to managing routing.

It is recognised that integration alongside end-hosts and IP applications is a critical element inherent in any networking protocol. When considering the fact that the majority of network settings utilise IP as standard, the importance therefore can be acknowledged in regards CPN's overall compatibility with IP [8]. On a number of different operating systems, including Linux, which is most commonly implemented across routers, most applications have their source code available. When this is the case, incorporating CPN support can result in a number of different yet simple amendments to the code, which establishes and connects a socket [8]. When recognising that the size of the address in the CPN is kept at 32 bits, the IP and CPN addresses are seen to be well-matched, thus meaning the ability to convert an IP application to a CPN one is a relatively simplistic process. When taking applications for which there is no available source code, even in such an instance, the CPN may still be adopted. Through taking the various socket functions, intercepting them and accordingly redirecting them to their CPN specific counterparts, there is the capacity for the application that has been written in mind of IP use to also use the CPN without any application side-outlined stipulations.

A further method that helps to bring together IP and CPN, as discussed in [8], is that of tunnelling, which is recognised as making changes to the IP routing table such that, prior to an IP packet being communicated across the wire, it first and foremost is encapsulated within the CPN packet. Such a process requires that a tunnel source and tunnel edge be designated; this role is adopted by an administrator. Through such an approach, conventional IP packets are able to tunnel to the CPN, thus facilitating uncomplicated, simple functionality across mixed IP and CPN networks. Through the implementation of an overlay network, CPN routing is able to offer a vast array of advantages, which can be incorporated into existing networks, complete with low costs and without the need to make changes to any underpinning routing mechanisms [8] . Accordingly, there is a clear and wide-ranging compatibility between the CPN protocol and the IP protocol; from an internal perspective, it provides dynamic routing in line with on-line monitoring and sensing. Moreover, the CPN technology also may be used to create and determine private user networks; these are incorporated in addition to existing TCP/IP, Asynchronous Transfer Mode or alternative forms of network communication.

2.9 Enhancements and Applications

When considering CPN in line with a number of different uses, it has been found to be effective; such uses might include power-based routing in mobile ad hoc networks, traffic balancing, denial of service (DoS) protection, and admission control (AC). With this noted, the present section provides an overview of the applications that utilise CPN protocol [6].

2.9.1 CPN in Wireless Networks (Mobile Ad Hoc CPN)

CPN architecture has also been incorporated into mobile networks [23], although in the case of mobile ad hoc environments, neighbouring nodes might make unexpected changes as a result of breakdowns in links, induced by node position change or environmental changes. In an effort to manage such a situation, the ad hoc CPN's SPs facilitate broadcast use, as well as unicast decisions' these solutions allow the ongoing exploration of the network whenever a node without information is reached or, alternatively, when neighbourhood information is found to be out of date [23].

Broadcast use facilitates SPs in making contract with all neighbouring nodes without there being any stipulation outlining the clear choosing of one. It further circumvents the need of a process geared towards neighbour-discovery that could make unnecessary use of network resources. The assumption is made by AHCPN that, when considering the neighbourhood, should the number of known neighbours be less than two when the traffic source is the node, then there is insufficient knowledge; when the source of the traffic is not the node, however, known neighbours of less than three can signify inadequate knowledge [27].

Importantly, those neighbours in receipt of the packet go on to repeat the decision process; therefore, a broadcast might again be used by the SP, or otherwise the SP might choose a particular neighbour for the role of continuing the exploration of the network. It is valuable to recognise that, overall, there is a preference of unicast decisions amongst SPs [60]. Notably, uni-casts offer a key benefit of a greater degree of reliability and the capacity to limit node numbers involved in the discovery of routes. In contrast, however, broadcasts may suffer from collisions, although a small random delay may be incorporated prior to a broadcast being transmitted; this is geared towards decreasing the overall likelihood of a collision. In this regard, AHCPN provides a clear definition of particular goals for wireless settings, with consideration towards energy consumption and link reliability as two main elements [6].

One of the key benefits to be derived from AHCPNs over such routing algorithms is that network state collection places emphasis on active paths as opposed to network-wide collection, thus meaning that the algorithm is able to make decisions with the information at its disposal[5, 24–27]. As the algorithm becomes better informed and has access to more information, the decisions made are more focused, meaning routes demonstrate greater efficiency in terms of QoS. Importantly, to a minor degree, broadcasts are used in order to manage unexpected network dynamics. QoS differentiation is provided by the algorithm so as to achieve best effort traffic without involving complexity in defining a resource reservation mechanism in the network.

2.9.2 Emergency Navigation with CPN

A new, cloud-based emergency navigation system that lends the concept of a CPN whilst almost making use of social potential fields [61] to evacuate civilians in built environments. As a software-defined network, CPN can be entirely applied in software, meaning it can be simply and easily implemented across cloud servers as virtual CPN nodes. Moreover, CPN is able to secure time-efficient adjustments owing to the fact that each CPN node functions as a sub-system in identifying the environment, without the need to incorporate synchronisation processes. Through this model, smart phones are used as clients to link cloud servers' access points, which implement intensive calculations. Evacuees thus are directed towards exists with the adoption of a cooperative approach so as to ensure communication and localisation improvements, in addition to increasing the potential for a civilian to find help whenever needed. A power-conscious QoS metric [62] which essentially is centred on the ad-hoc cognitive packet network (AHCPN) protocol [23] and which utilises an energy-aware sensible routing approach [63] is further presented in an effort to extend smart handset lifetimes. One key benefits of this particular protocol is that it is able to identify malicious users, with in-depth path information stored in the packets of the route-search. Accordingly, upon the occurrence of an emergency, a few cloud access points may be quickly implemented between emergency locations, with the evacuees using only a smart phone, which provides an energy-efficient ad-hoc network, thus enabling access points to be reached so as to achieve two-way communication [6].

A cloud-facilitated indoor emergency navigation model has been presented by the author in an effort to direct evacuees in a time-efficient and productive manner and to enhance the overall resilience and reliability in regards both localisation and communication. Through combining different social potential fields a cognitive packet network-based algorithm, evacuees are directed towards exits in loose clusters. As opposed to depending on a traditional telecommunications approach, the suggestion is to use an ad-hoc cognitive packet network (AHCPN)-based protocol so as to facilitate adaptively searching optimal communication routes between portable devices and the network egress nodes that provide access to cloud servers, in a manner that spares the remaining battery power of smart phones and minimises the time latency. The results of the experiment, as garnered through in-depth simulations, show that smart network management combined with smart human motion can improve evacuees' survival rates and accordingly decrease the number of smart phone battery consumption in evacuation processes [6].

Use the A Cooperative Emergency Navigation Framework using Mobile Cloud Computing, A cloud-facilitated *emergency navigation model* has been presented by the authors [64] in an effort to direct evacuees in a more reliable, resilient and coordinated manner, notably in terms of communication and localisation. Through the use of SPF (Social Potential Fields), evacuees form clusters throughout the course of an evacuation, and are directed with the use of a CPN-based algorithm. As opposed to merely depending on traditional telecommunications models, an AHCPN-based protocol is suggested as able to extend the lifetime and battery consumption levels of smart phones, with access to a cloud service provided, which improved remaining battery power levels and time latency [64] .

2.9.3 Traffic Engineering with CPN

CPN utilisation in mind of satisfying traffic engineering (TE) objectives is explained in [65] , with TE recognised as facilitating ISPs (internet service providers) in achieving resource utilisation and network performance optimisation. In specific consideration to CPN technology, an ISP has the ability to deliver value-added IP services, including QoS, across its base of customers, whilst also carrying out TE across the network. In regards end users, CPN is well positioned to deliver QoS at the application layer, in line with delay limitations, and also at the service level, at which traffic is redistributed in a flow-basis across the nodes located at the edge, notably in much the same way as Resource Reservation Protocol (RSVP) and IntServ. Accordingly, congestion at the link level is minimised by the network, with the delay experienced by packets also minimised. Importantly, the authors of the work of [65] further detail experimental findings in regards the ways in which ISPs are able to satisfy TE-related stipulations through CPN utilisation [6].

2.9.4 Hardware Implementation of CPN

CPN utilisation alongside the routers currently applied in internet-based network architectures have the ability to induce restrictions as a result of greater rates of traffic incorporated within the networks, whilst simultaneously witnessing increases in packet processing demands. Accordingly, CPN protocol hardware implementation would be well positioned to deliver a more efficient and less costly solution than packets. The key issue in this regard, however, relates to the intricacy and the memory requirements in regards RNN with RL. The hardware implementation of the RNN-based routing engine of a CPN network processor chip, referred to as the SPP (Smart Packet Processor), is discussed in the work of [66]. Importantly, the SPP offers a dual port device; this is responsibility for taking the defining characteristics of individual RNN models and accordingly storing, modifying and interpreting them. In this vein, the authors of the work [66] provide the recommendation that hardware design improvements should be prioritised over software application, as in the case of the dual access memory, decreased output calculation model, output calculate stages, and the presentation of a modification over the reinforcement learning random neural networks. Importantly, a number of simulations have been carried out in [66], with specific focus on isolated SPPs design' functionality, in addition to multiple SPPs in a networked setting. A number of other algorithms besides RNN have also been suggested in other works [67, 68] in an effort to ensure the advantages associated with RNN are derived, but with a less complicated nature and lesser need for resources; this positions such algorithms as more suitable in the field of hardware implementation. The estimated RNN (aRNN) [68] is not a neural network, but rather seeks to estimate RNN properties whilst utilising only simplistic arithmetic functions, namely subtraction and addition, and bitwise shifts.

In this vein, an alternative routing policy, as discussed in [63], referred to as $1-SR$ (a sensible routing(SR)), centres on making routing decisions in line with the expected QoS of a potential outcome and accordingly chooses the expected path's QoS metric. In the case of an $m-SR$ policy, there is an increase of the inverted expectation of the QoS metric to the power of m; this is done so as to ensure the overall likelihood of choosing the best performing route is increased. Accordingly, the RNN's issue of costly divisions, both in regards the probability calculations and the inversions, is shared by the $m-SR$. Nonetheless, should the $m \to \infty$ the likelihood of choosing the best route equals

1, the application is then made simpler. Accordingly, through circumventing divisions, the $\infty - SR$ and the estimated RNN provide faster yet smaller implementations when contrasted alongside the RNN. Furthermore, they also do not need as much memory, and demonstrate improved scaling with regards the number of neighbours. This provides a further advantage owing to the fact it positions the CPN as far more suitable and further facilitates its use in software-motivated devices that otherwise might be lacking in powerful processor capability and memory, as in the cases of wireless sensor network devices and PDAs, for example. With this noted, the writers of [67, 68] further suggest a field programmable gate array-based hardware CPN router be designed. Accordingly, this design emphasises that the more conventional architectural approach applied in high-speed IP routers are applicable to CPN routers; this further highlights the potential for hybrid IP/CPN routers in hardware [6].

The use of hardware virtualisation is examined as an experimental instrument centred on enhancing the efficiency of resources and facilitating node availability number effectiveness for network testing [69]. Through the virtualisation of network links and routers, there is the potential for a cluster environment to host several hundred virtual routers to facilitate large-scale network testing. Such a method may be applied in order to create a CPN test-bed with 800 nodes, which, in turn, can give understanding into the various limitations and benefits of the approach [69] .

2.9.5 The Cognitive Packet Network in A Software Defined Self-Aware Network

The CPN, which is a good example of both a self-aware computer network, referred to as a SAN, and a software defined network, referred to as an SDN, has been widely applied and utilised in a number of different experiments. CPN has the ability to observe its own internal performance, in addition to the interfaces of external systems with which it interacts, in an effort to make changes to its behaviours so as to achieve objectives, such as identifying user services, enhancing QoS, decreasing energy consumption, identifying and responding to intrusions, compensating for elements that might fail, and defend itself against attacks. [70].

2.9.6 Cognitive Routing Engine for Software Defined Networks

The majority of SDN (software defined networks) traffic engineering applications utilises continuous and excessive global monitoring when seeking to identify the most efficient QoS paths.[71] In this work, the architecture, motivations and initial assessments of an SDN application referred to as CRE (Cognitive Routing Engine) are presented; this framework is able to determine near-optimal paths for a user-specific QoS whilst implementing a small monitoring overhead when contrasted alongside global monitoring; this is necessary when seeking to ensure optimal paths are identified. Smaller monitoring overheads create the benefit of a quicker response time across SDN switches and controllers, with the initial CRE assessment centred on an SDN representation of the GEANT academic network emphasising the potential to identify almost entire optimal paths with a small optimality gap of 1.65% whilst utilising 9.5 times less monitoring[71].

2.9.7 CPN in Sensor Networks

A number of different devices, notably of restricting memory, energy and processing ability, are inherent in wireless sensor networks. The author behind the work [72] suggests a less complicated CPN-based routing protocol for sensor motes, which utilises smart routing in an effort to limit the transmission power use, whilst also aggregation data's on-line aggregation in line with mote locality. The tinyCPN protocol monitors and oversees message success in reaching the sink, the route length they identify, and the necessary power. In much the same way as the wired CPN version, in the tinyCPN smart messages, the aim is to determine a reliable low-power route. The neighbour with the lowest recorded energy requirements receive the messages, which are then forwarded to the sink, at which point a smart acknowledgement message is communicated across the same pathway and back to the source. The route power requirements and routing tables are updated for the sink across all of the route's nodes.

In comparison to the CPN, aside from end-to-end acknowledgements that are communicated when smart messages communicate to their destinations to provide updates across QoS tables and routing, there is also the use of hop-by-hop acknowledgements whenever a node receives a message. As a result of the fact that the likelihood of message loss or corruption during the transmission process is greater across sensor networks, upon receiving a message, a node immediately responds to the previous hop with acknowledgement on a hop-by-hop basis. Importantly, should no acknowledgement be forward, the message then may be resent. Whenever a message is resent, it is recorded, with the number of resends used as a multiplier when establishing the hop-by-hop route power stipulations for smart messages. Importantly, whenever data is carrying a dumb message and this is sent, it may be that a smart message will also be sent. This helps to facilitate the constancy of route data and power [72].

2.9.8 Defence Mechanisms Against DoS Attacks in CPN

Acknowledging the fact that future networks will encompass on-line user interaction and self-awareness amongst users, some authors [73] have examined defence techniques application in regards the overall resistance of CPN to DoS attacks. Importantly, a general model focused on DoS protection has been presented, in line with the decline of likely illegitimate traffic, with a mathematical framework presented, which has the capacity to measure and calculate the effects that both defend and attack actions have on network performance. From a more deeply analytical perspective, the CPN-based distributed DoS defence method makes use of the overall capacity of the CPN to monitor and trace traffic travelling both upstream and downstream, as a result of ACK packets and SPs.

Upon identifying an attack, a node then uses the ACKs to request that all intermediate nodes upstream to drop the attack flow packets. It is permitted that all nodes choose the greatest possible bandwidth possible from any flow that terminates at the node, and the best bandwidth that it assigns to a flower that traverses the node. Such parameters may be seen to differ significantly in line with various other conditions and parameters, and they also may be chosen in line with the flow identity and its QoS requirements. Upon receiving a DP or an SP from a flow that, previously, has not been utilised (e.g. with a new source destination pair, or a new QoS class), a node then communicates a Flow-ACK packet to the source, utilising the same path but in reverse, and further communicates the bandwidth allocation source. The flowers traversing it are monitored by the node, and any flow recognised as exceeding the allocation will have its packets dropped; upstream nodes may also be informed that this particular flow's packets should be dropped. Other potential courses of action might include redirecting the flow to a special network or 'honey pot'.

As is recognised when reviewing the findings of [73], the mathematical findings were validated with experimental measurements and simulation results in a CPN environment. Such a generic defence experienced further enhancements through the adoption of rate-limiting methods and prioritisation as opposed to simple dropping [74, 75]. In an effort to achieve further enhancements in terms of DoS attacks resilience, the same authors further presented a DoS-identifying tool, which utilises on-line statistics gathered through the monitoring system of the CPN protocol, which then are fused with an RNN [76] . From a more analytical perspective, the scheme further utilises input features focused on gathering not only the instantaneous behaviour but also traffic information in regards more long-term statistical elements. When considering information-gathering in the off-line stage, probability density function estimates are gathered, whilst also assessing the potential ratios in regards input features. Throughout the decision stage, which is carried out in real-time, incoming traffic features are measured and calculated, which determines the overall likelihood ratios in line with those values, and further aggregates the most likely values with the use of an RNN. The architecture as a whole outputs a numerical value that is a measure of having a continuous network attack; as a result, this is used in rate-limiting and prioritisation mechanisms, as highlighted previously [77, 78].

2.9.9 Strengthening the security of cognitive packet networks

Related network security threats have been examined by the authors [79], with a number of tools suggested as potentially improving CPN resilience in terms of availability, integrity and confidentiality attacks. Potential CPN weaknesses have been analysed, along with the adoption of RNNs in relation to availability, integrity and confidentiality, with solutions potentially able to improve CPN resilience taken into account in relation to representative security threats [79].

2.9.10 CPN with Sorting

When reviewing the original CPN application, the route brought back by the ACK of an SP is recognised as the most beneficial one and may be used by the data traffic; however, this can result in unsuitable performance across the data packet owing to the fact it does not take into account *SP* exploration's more random element, where each router, to a small degree, could select a random subsequent hop for an SP as opposed to that chosen by the RNN. Accordingly, there has been the suggestion made [80] that route quality brought back by an ACK packet be compared alongside the present route, with routes switched only when the new route's reward is more beneficial than that of the present route. This version has been referred to as 'CPN with Sorting'; associated experiments indicate that there is better performance than the original CPN algorithm [6].

2.9.11 Big Data for Autonomic Intercontinental Overlays with CPN

CPN utilisation alongside big data and machine-learning in the real-time management of internet QoS route optimisation is recognised as valuable with an overlay network[81]. In line with the data sampled collected every two minutes across a significant number of source–destination pairs, it can be seen that IP paths are nowhere near efficient enough with regards QoS metrics, including end-to-end round-trip delays. Accordingly, a machine-learning based initiative has been devised in mind of utilising large scale data, gathered from communicating node pairs in a multi-hop overlay network, which implements IP between the overlay nodes, and accordingly chooses paths that are able to deliver higher QoS than IP. Designed in consideration to cognitive packet network protocol, random neural networks are used with reinforcement learning in consideration to the large volume of data gathered, in choosing intermediate overlay hops. The routing scheme is highlighted with the use of a 20-node intercontinental overlay network[81].

2.9.12 Recursive CPN

A QoS-based recursive routing algorithm has been suggested in the work of [82] , where such an algorithm is centred on breaking a large-scale routing issue into more manageable pieces. In the intermediate nodes, partial routes are cached; these then may be directed towards providing a fast predication concerning the most appropriate and efficient QoS-based routes required by an arriving packet. The experiments carried out were done on a network test-bed comprising 46 nodes, with the results demonstrating that, with the application of recursive routing, the average duration for an SP to identify a valid route is significantly decreased, with more routes identified by the SPs. They further highlight that choosing paths in line with QoS as opposed to data freshness does not decrease overall CPN adaptability but actually can enhance the QoS experienced by users; this is achieved through suggesting only the most appropriate routes.

2.9.13 Routing Diverse Evacuees with CPN

A multi-path routing algorithm has been introduced, which seeks to fulfil all stipulations inherent in diverse evacuee classes. Such a method is centred on the CPN, which has reviewed in search of optimised routes rapidly and adaptively with regards QoS goals so as to assess the overall quality of paths and accordingly select the best routes for different evacuee groups. In an effort to ensure congestion levels are minimised, a congestion-aware algorithm with the capacity to estimate future traffic is suggestion. In this vein, it is stated that direction oscillation issues occur in adaptive routing with sensitive metrics as a result of delays in available information, with movement depth recognised as able to encourage evacuees to update their routes on a regular basis to as to ensure hazard avoidance [83].

2.9.14 Energy-aware Routing in the CPN

An EARP (energy aware routing protocol) is presented in this work, which seeks not only to decrease the total power consumed in the network, but which also considers the QoS in line with all incoming flows. The EARP depends on the CPN for the information it requires, and accordingly utilises such information so as to decrease consumption in power. The smart packets of the CPN are used to gather information relating to power usage at the nodes, with EARP implemented in an entirely distributed way using the source routing scheme of CPN, as amended so incorporate a criteria relating to power consumption. The experimental test-based that utilises EARP underwent measurement, with such results presented and found to suggest that power consumption can be reduced when contrasted alongside the approach utilising only QoS level[84].

2.9.15 Cognitive Packet Network for Bilateral Asymmetric Connections

Through the approach suggested in this study, all CPN edges or other user nodes are simultaneous sources and destinations, with the management of uplink user-centred traffic and downlink traffic sent back in response. Such a two-way communication is carried out across four individual QoS aims, all of which may be satisfied between sender nodes. Asymmetry in traffic volume, between both sent and received data, is used to induce QoS-related changes, with the lower traffic rate necessitating short-delay QoS, whilst the higher traffic rate necessitates loss minimisation [85].

2.9.16 Real-Time Traffic over the CPN

CPN utilisation alongside Real-Time services over IP (RTIP) have become more and more important as a result of data networks convergence, witnessed on a global scale, combined with widespread internet use. Such applications have been assigned with strict QoS limitations, which have induced key obstacles in regards IP networks. The CPN has been designed in such a way that QoS-driven protocol deals with user-oriented QoS demands through adaptively routing packets based on online sensing and measurement. Accordingly, in the present work, the RT is evaluated, from design and experimental perspectives, in contrast with CPN protocol, which is known to utilise QoS goals that are aligned with the needs of real-time packet delivery in the presence of other background traffic in various traffic conditions. The design undergoes evaluation through attention to packet delay, packet loss ratio and delay variation (jitter) measurements [86].

2.9.17 Admission Control with CPN

CPN is recognised as providing QoS-based best-effort routing; this means that users may be limited in securing the network service they need in order to achieve operation success when there is network congestion and high demand. One way of overcoming this issue, notably through controlling traffic congestion, would be through AC. Various authors [87, 88] have made the recommendation of a centralised, measurement-based, multiple criteria AC algorithm focused on QoS metric measurements in line with each network link. Importantly, owing to the fact that CPN already gathers QoS-related information across all paths and links explored by the SPs, as well as across all paths used by a user in the network, there are no special stipulations or criteria. One of the key advantages to be garnered from the suggested AC algorithm includes the fact that users are able to outline the QoS criteria for obtaining the network service needed in order to achieve success connections; this enables users to outline different QoS criteria and QoS values as necessary [6].

This particular initiative makes the choice as to whether or not a new call may be permitted network entrance in line with the QoS metrics measurements across all network links, both prior to and following probe packet transmission. In contrast to present approaches, this scheme predicts the effect of the new flow through probing at a small rate; this means that the network's congestion will not be overly affected by the probe packets. Lastly, the choice as to whether or not a new flow will be permitted is made in line with an algebra centred on QoS metrics, founded on the algorithm of Warshall's [89], which seeks to establish whether or not there is a practical path able to accommodate the new flow without inducing any impact for existing users. The efficiency of the algorithm within significantly congested circumstances is demonstrated through experimental results, notably with the use of a 46-node real test-bed [90] .

2.9.18 Autonomic Auctions and CPN

The role adopted by CPN in future network-based markets, in which autonomic auctions will be one aspect of the web-based economy, is explained in various works [91, 92] . The auctions that are taken into account are those that are seen to encompass network auctions in which any bidder, with the exception of that which has made the most recent bid and is awaiting seller response, is permitted to move from one auction to another at any stage. The works of [93, 94] provide a mathematical analysis of automated network auctions, with the authors analysing various types of auction, both in regards the price that will be achieved and the per-unit income provided. Importantly, the method provides mathematical frameworks centred on the automated sellers and bidders using a network.

A network market, in this regard, is seen to be composed of various CPN nodes, all of which may have different geographic situations, with the network able to provide information pertaining to how, when and where users should purchase or sell items. Importantly, application-level requirements, including price-related elements, along with network-level considerations, such as communication, for example, may be taken into account [92, 95, 96]. Choices might be made in line with algorithms that are based on 'sensible decisions', as examined in the work of [97] , where predictions are made in line with the probability that combine auction-specific factors and network or routing factors. Accordingly, with the CPN protocol, all users, whether buyers or sellers, when involved in a network auction, would adapt their behaviour in line with auction- or network-based heterogeneous factors.

2.9.19 CPN and Next-Generation Battle-Space Information Services

As has been discussed thus far, the CPN protocol is applied when seeking to make choices in regards an agent-based architecture's communication layer, as in the case of the HYPERION project, initiated by the UK Ministry of Defence, with the objective to derive an adaptive and automated information management tool with the ability to be incorporated into defence networks [97]. The general system architecture has been devised in such a way so as to enhance field commanders' situational awareness through delivering the potential to compose and fuse together information systems. The main technologies implemented in an effort to facilitate such a goal include autonomous software agents, a smart data-filtering system, a 3D battle space simulation environment, and self-organising middle-ware. Importantly, the CPN's role, in specific regard this project, is focused on delivering an adaptive network architecture with greater resilience for battle space communication networks and related information services. Owing to the fact that network security is fundamental in such cases, the DoS defence mechanism outlined in an earlier section is a critical element in this project.

2.10 Experimental Performance Evaluation

With the exception of the individual experiments carried out in line with all of the applications and improvements detailed in prior sections, investigation into CPN for a whole host of purposes has been in-depth and thorough, in consideration to various performance measurements. All performance assessment work has been completed with the use of a real networking test-bed, with CPN implemented as a module of the Linux kernel [6].

2.10.1 Adaptability

CPN, in specific consideration to its ability to adapt to changing network conditions, whether buffer overflows, link failures or traffic load, has been the focus of much evaluation [25]. Through the completion of different experiments, it has been established that CPN has been successful in identifying new routes when seeking to circumvent obstructing traffic, as recognised in some of the links utilised by data traffic, as well as those experiencing failure. One further issue that has received experimental examination in [25] pertains to the effects of the SP–total packets ratio in regards CPN's overall performance. The conclusion was drawn that, in an effort to achieve the best performance in DPs, there is a need for SPs being sent for discovery to be in the range of 10–20 % of data packet rate. When expanding beyond these values, DPs' QoS values are not significantly improved; this has been afforded much further examination in [26], with experimental data highlighting that, when seeking to satisfy the QoS goals of users, a small fraction of SPs and ACKs, compared with total user traffic, is necessary. There is a need for one to consider that, in CPN, ACKs and SPs are not full-sized Ethernet packets; rather, they are more like 10% of the size of the DPs. Should SP traffic be added to the rate of 20%, this would cause traffic overhead equal to approximately 14%, when there is the generation of ACKs in line with SP response. Furthermore, it has been found that only a small number of SPs would be adequate in determining a connection. As well as the experiments carried out on the test-bed in the work of [26], a number of other simulations have been implemented across a 1000-node network; the findings are generally equivalent to real experiments.

2.10.2 QoS Goals

In specific consideration to packetized voice applications, the choice of a goal and reward are taken into account in [19], along with the presentation of experiments carried out for 'voice over CPN'. CPN performance is examined in greater depth through the application of different measurements, with the resulting QoS undergoing comparison with IP routing protocol, ensuring the same conditions, and accordingly achieving gain from CPN use.

The way in which the CPN protocol can react to various QoS goals is detailed in [20, 22], along with measurements. There is the proposition of composite goal functions, whilst ensuring attention to both delay and packet loss. Furthermore, in the work of [22], there is the suggestion that CPN networks are most effective in adapting to routing behaviour in line with the QoS goal outlined; this can be seen when reviewing the measurements. Furthermore, experimental results are also detailed in [20] when GA is applied in an effort to establish new routes from the information identified through SPs. The findings emphasise that the GA daemon further enhances QoS when network traffic conditions are seen to be light; when traffic is high, however, this is not the case. The authors, in this regard, provide a justification that the GA tends to delay decision-making owing to the fact it holds a greater abundance of information and makes suggestions in line with more long-term patterns.

2.10.3 Realistic Environments

A number of experiments have been carried out and detailed in [80] explaining the performance of CPN in a realistic setting, comprising a 46-node test-bed. CPN performance was contrasted alongside industry-standing routing protocol, namely the open shortest path first (OSPF) routing protocol, which is widely implemented in IP networks. A real-world topology was used, notably the Swiss Education and Research Network (SWITCHlan); this is used on a wide-ranging scale in Switzerland, particularly across various education sites and in different universities. This network's administrators provide a number of details on their 46-router foundation, with information pertaining to OSPF costs, bandwidth and link-level delays. Moreover, owing to each link's costs, OSPF routing converges to the minimal delay path, which therefore provides a key comparison measure. The experiments further highlight that the routes calculated through CPN are just as valuable as those garnered a priori through the use of administrator-defined costs. Moreover, the paper provides experimental findings, indicating that, an RNN alongside RL, has the capacity to autonomously learn the most valuable route in the network, with this achieved simply through quick exploration, with the CPN protocol therefore highlighted as being able to quickly adapt and make changes in line with the network environment, such as through identifying and changing to the network's most optimal route. It has also been seen through the conduction of the experiments that the original CPN algorithm may be enhanced when data-traffic is re-routed upon identifying a more efficient route.

2.10.4 Intermittent Node Failures

As can be seen in the work of [98] , CPN performance is contrasted in the presence of intermittent node failures, as induced by a network worm and its spread, with that of the routing protocol OSPF. The findings demonstrate that CPN is able to perform in a more efficient way when the OSPF routing method, notably through demonstrate quicker adaptability to the network changes and thus circumventing failure-induced congestion and avoiding failed nodes, whilst simultaneously maintaining the average delay experienced by users at a lesser level. Furthermore, failure identification is also recognised in the work of [98] as being able to improve CPN resilience when there is the failure of nodes.

2.10.5 Routing Oscillations

Despite the fact that oscillations overall are recognised as a network weakness, it has been shown through performance evaluations that routing oscillations do not have a notably significant impact on performance, as can be predicted, with high performance still achievable even when oscillations are identified [99, 100]. notably can be controlled, with two different parameters recognised as having a notable effect on oscillation rate undergoing examination, namely the adoption of probabilistic path-switching, which may be utilised in line when seeking to make path-switching more asynchronous, as well as when seeking to vary the rate at which switching decisions are made, and the implementation of a decision threshold, which further facilitates path-switching should the switching gain be seen to exceed a minimal value. Such control schemes are easily applied and provide an efficient approach to minimising oscillations and their consequences; however, the question is raised as to whether negative consequences in routing protocols are found when there are self-monitoring adaptations, as in the case of the CPN protocol.

2.11 Power Control Algorithms Adapted Towards Ad-hoc Cognitive Packet Networks

2.11.1 Introduction

The key objective underpinning the power control algorithm in mobile ad-hoc networks is to satisfy performance criteria, such as in regards network connectivity, for example. Not only can network capacity be improved through such a means, but so can the battery capacity of nodes. Accordingly, power control algorithm is recognised as a important consideration in the case of mobile ad-hoc networks. Should there be no central node charged with power control administration, network topology improvement would be far more difficult in ad-hoc wireless networks. Moreover, should ad-hoc networks comprise many thousands of nodes, gathering information from nodes and accordingly communicating it to the nodes concerned would ultimately result in significant overhead. As such, distributed topology control algorithms notably those that are asynchronous, localised and scalable are viewed as being especially appealing in ad-hoc networks. In addition, in an effort to ensure deployment and reconfiguration are as uncomplicated as possible, the power control algorithm needs to adapt to the surrounding node density, as well as in line with mobility and the physical environment. In this vein, Pradhan and Saadawi [101] recognise that a mobile ad-hoc network's overall performance and topology rely on both node mobility and the physical environment. As such, in this vein, a key argument is posed by Pradhan and Saadawi [102] suggesting the use of a adaptive distributed power control algorithm with the capacity to create a well-linked network with adaptability in regards changing network conditions.

In mind of the above, this chapter will discuss a number of different methods focused on managing power control in the case of mobile ad-hoc networks. Furthermore, the approaches will be categorised into Node-Degree Constrained Approach, Location Information-based Approach, Graph Theory Approach, Game Theory Approach and Multi-Parameter Optimisation Approach. Moreover, an example of a Multi-Parameter Optimisation approach, referred to as DISPOW algorithm, As has been recognised, the generic network layer power management algorithm DISPOW delivers a well-connected network that is energy efficient and customised in line with the surrounding node density, node mobility and physical environment.

2.11.2 Multi-parameter Optimisation Approach

One other suggested method is a dynamic multi-parameter optimisation concerned with other parameters, including energy consumption, connectivity and interference across the network. A localised algorithm DISPOW, which is able to develop a strong connected network topology in a customised and distributed way, may prove useful to its propagation and node density environment. Importantly, it offers the ability to adapt to the changing network topology as a result of the dynamic physical environment and node mobility. Importantly, adaptive Distributed Power management algorithm (DISPOW) is recognised as encompassing a receiver-based interference framework, which seeks to decrease internode interference, but also has the ability to concert asymmetric links; this is a key obstacle facing symmetric links. With this taken into account, it is important to acknowledge that DISPOW, through its distributed way of operating, can be easily applied to largescale heterogeneous networks and is scalable[103].

2.12 Summary

One of the key benefits to be derived from AHCPNs over such routing algorithms is that network state collection places emphasis on active paths as opposed to network-wide collection, thus meaning that the algorithm is able to make decisions with the information at its. As the algorithm becomes better informed and has access to more information, the decisions made are more focused, meaning routes demonstrate greater efficiency in terms of QoS. Importantly, to a minor degree, broadcasts are used in order to manage unexpected network dynamics. QoS differentiation is provided by the algorithm so as to achieve best effort traffic without involving complexity in defining a resource reservation mechanism in the network. Present power-control method in the ad-hoc cognitive packet network network essentially apply deterministic or probabilistic techniques in creating network topology that fulfils particular metrics, whether reduced interference, maintained network connectivity, or QoS. Earlier power control methods introduced in the arena of power control have essentially focused on and attempted to establish a complete set of node transmission power with the aim of reducing total power consumption.

In the specific case of an ad-hoc cognitive packet network comprising many different nodes, there are many complications associated with calculating the best transmission range for all nodes. Moreover, gathering information in regards to all nodes and accordingly passing them to the nodes concerned could result in significant overheads. Furthermore, ad-hoc cognitive packet networks, in contrast to cellular radio systems, do not offer a central scheduler, meaning there is a need for power control algorithms to be localised and scalable.

Chapter 3

APPLICATION OF DISPOW WITH AD HOC COGNITIVE PACKET NETWORKS

3.1 Introduction

Mobile ad hoc networks (MANETs) are recognised as a group of two or more devices, whether terminals or nodes, encompassing wireless communications and offering networking capacity, with the ability to communicate with one another without centralised infrastructure assistance. Nodes in such a network, whilst also adopting the role of end systems, further act as transit nodes for other communications. The involvement in the searching for and identification of paths, and subsequently forwarding packets, ultimately depends on internal resources and the availability of such. These resources generally tend to be lacking owing to the nodes' mobile nature. AHCPN [23, 27] is recognised as an innovative routing protocol intended for ad hoc networks. The Cognitive Packet Network (CPN) [24, 4, 25, 5] functions as a fast, adaptive routing algorithm that directs learning, in effect, to identify and refine routes. Routes are established and maintained by Smart Packets or Cognitive Packets, which are communicated by sources nodes upon the recognition of the need for a new destination. Smart packets (SPs) move in the network, gathering data and making choices that further take into account what has been learnt by other nodes. Decisions may be changed and shaped so as to highlight a desirable level of QoS on the path, such as by minimising power consumption or end-to-end delay.

The key objective underpinning the power control algorithm in mobile ad hoc networks is to satisfy performance criteria, such as in regard to network connectivity, for example. Not only can network capacity be improved through such a means, but so can the battery capacity of nodes. Accordingly, the power control algorithm is recognised as a critical consideration in the case of mobile ad-hoc networks. Should there be no central node charged with power control administration, network topology improvement would be far more difficult in ad-hoc wireless networks. Moreover, should ad hoc networks comprise many thousands of nodes, gathering information from nodes and accordingly communicating it to the nodes concerned would ultimately result in significant overheads. As such, distributed topology control algorithms, notably those that are asynchronous, localised and scalable, are viewed as being especially appealing in ad hoc networks. In addition, in an effort to ensure deployment and reconfiguration are as uncomplicated as possible, the power control algorithm needs to adapt to the surrounding node density, as well as be in line with mobility and the physical environment. In this vein, Pradhan and Saadawi [101] recognise that a mobile ad hoc network's overall performance and topology rely on both node mobility and the physical environment. As such, a key argument is posed by Pradhan and Saadawi [102] suggesting the use of a distributed power control algorithm with the capacity to create a well-linked network with adaptability in regard to changing network conditions.

In this chapter, ad hoc networks, nodes create dynamic topologies, with very limited resources, such as bandwidth and energy. In much the same way as other routing protocols, the Ad Hoc Cognitive Packet Network (AHCPN) conventionally applies a fixed transmission power, which is able to achieve reliability in links' connectivity. *In this chapter*, we use a power control algorithm, namely the adaptive Distributed Power management algorithm (DISPOW), devised as a network-assisted functionality of ad hoc cognitive packet-based routing as a first time. The proposed routing protocol is based on an adaptive, per packet, transmission power control scheme. In which a certain target of Signal to interference plus noise ratio (SNIR) value and Quality of Service (QoS) is maintained. This scheme is concerned with realising path loss of signal through drawing a comparison between the power that is transmitted, which is in the header of the packet, against the power that is received by a certain node.

The signal power required for achieving a reliable link transmission to each of the neighbour nodes is calculated and preserved within the packet header through each packet exchange process between any adjacent nodes. The power control algorithm DISPOW is to ensure energy consumption conservation, network connectivity, and a lesser degree of interference.

Simulation results in network simulator 3 (NS-3.24) show that the proposed routing protocol overcomes the previous one in terms of Delay by almost 27%, Throughput by around 13%, Packet loss by nearly 9%, and Energy consumption by almost 40%

3.2 Research Gap

Adaptive Fidelity Algorithm (AFA) [104], functions in addition to on-demand ad hoc routing protocols, as in the cases of An Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR). AFA provides battery power savings by ensuring particular transceivers are turned off whenever a reduction in the quality of connections is allowed by the applications. The algorithm offers a trade-off between quality and battery lifetime, network bandwidth and various active sensors.

The work of Singh, Woo & Raghavendra [105] has presented a new algorithm concerned with achieving power consumption savings in the case of mobile ad hoc networks through the application of a passive energy saving method. A number of different metrics were presented in line with battery power that may be able to decrease the routing costs from 5-30% when compared with short-hop routing. In controlling the power-off mechanism of that mobile node, Power Aware Multi-Access protocol (PAMAS) is a MAC layer protocol, the main concept underpinning which is that, as there is energy wasted, PAMAS is able to save between 40% and 70% of battery power through ensuring the node's radios are switched off during periods of non-transmission or non-receiving.

The majority of the preliminary methods are centralised and seek to determine a complete set of transmission power for nodes with the aim of decreasing overall power consumption. An alternate method is focused on identifying Transmission power for nodes, where network connectivity is preserved. Two distributed algorithms, namely LILT and LINT, are presented in [106], and adjust the transmission power of nodes with the aim of maintaining the required connectivity.

Other suggestions have been successful in overcoming the aforementioned obstacle through the use of battery lifetime data. Toh [107] suggests a new metric, which examines the summation of the remaining battery capacities; inverses of the path's nodes. Furthermore, the suggestion was made by Toh that the Min-Max algorithm could be directed so as to maintain the suitable use of resources by circumventing the adoption of those nodes with a low level of battery capacity in the network. In a similar regard, the study by Li et al.[108] suggests an algorithm that is able to calculate paths with minimal energy consumption whilst simultaneously maximising the network's minimal residual power.

The Power-aware Source Routing (PSR) [109] destination determines the link cost in line with the battery capacity remaining and the nodes' transmission power. In this case, the disadvantage is that the destination is required to wait for a period of time following the first route request's arrival in order to ensure more than one possible route can be received, with the one with the minimum cost then being chosen.

In the case of the Minimum Spanning Tree (MST-based algorithm) [110], all of the nodes build their local MST on an independent basis, with only on-tree one-hop nodes kept as neighbours.

In the case of [111], nodes choose a common transmit power, where the communication graph can be linked with at least k-neighbours over a uniformly distributed network.

Another suggested energy-aware routing algorithm is EAAR [112], the concept of which is based on the naturally occurring foraging behaviours demonstrated by ants. Such a concept can be contrasted with AODV and min-max battery cost routing (MMBCR) algorithm in regards energy conservation capacities. In contrast, a drawback can be seen in terms of the average energy per packet, which, in the case of high mobile conditions, is not desirable. Importantly, there is a high delivery rate in EAAR owing to the fact that the time taken for judging the most optimal route is high.

A routing protocol referred to as Power Aware Ad-hoc On-Demand Multipath Distance Vector (PAAOMDV) has been presented by Rajaram and Sugesh [113], which provides an optimum path between the power-saving path and the shortest path. One of the benefits is that the Energy Reservation Table (ERT) may be applied rather than the route cache. Importantly, it considers only the energy warranted in the future. In contrast, however, there is the drawback that the update in the table warrants additional overheads, meaning there is an increase in the average energy per packet.

A number of different power control algorithms, as outlined in [114, 115] have been considered in the work of Kawadia et al., with COMPOW and CLUSTERPOW recognised as the two identified algorithms. COMPOW is concerned with decreasing the transmission power of a particular node to the minimum level, where there is no change witnessed in the number of neighbours. In contrast, CLUSTERPOW consumes the lowest transmit power level ρ, whereby the destination is reachable (in multiple hops) through the use of a power level no larger than ρ. Both COMPOW and CLUSTERPOW are known to decrease the consumption levels of power at the node, with the battery life demonstrating increases; however, in such algorithms, thus far, there has been no other quality of service goal outlined. Importantly, battery lifetime is traded for delay in the case of CLUSTERPOW.

An adaptive distributed power management (DISPOW) algorithm has been presented by Pradhan & Saadawi [102] as outlined by this chapter, which, with its suitable power levels, is able to offer a well-connected reliable network, decreases interference and routing overheads, and ultimately delivers a shorter packet delay, alongside network throughput improvements, equal to as much as 37%.

3.3 Power Control Management in Mobile Ad hoc Wireless Networks

When considering the topic of mobile ad hoc networks, abstract power control algorithms are a critical consideration because they may enhance the overall lifetime and capacity of a network. There are a number of different methods and techniques for managing power control in the case of mobile ad hoc wireless networks. Each of the methods considered will be categorised into five key groups, namely Node-Degree Constrained Approach, Location Information-based Approach, Graph Theory Approach, Game Theory Approach and Multi-Parameter Optimisation Approach. Furthermore, attention will be directed towards the adaptive distributed power management (DISPOW) algorithm, which provides a key example of the multi-parameter optimisation method that manages node Transmission power in the case of a wireless ad-hoc network in Order to maintain network connectivity whilst minimising interference. Furthermore, the algorithm will be shown to have the capacity to create an individual and stable network topology customised in line with its propagation environment and surrounding node density over random topologies in a dynamic, mobile, wireless channel.

3.3.1 Multi-parameter Optimisation Approach

An example pertaining to multi-parameter optimisation approach algorithms has been provided, namely adaptive Distributed Power management algorithm (DISPOW), which completes nodes' power management in a dynamic wireless ad hoc mobile network with the aim of ensuring energy consumption conservation, network connectivity, and a lesser degree of interference. DISPOW is able to create a well-connected network in line with the surrounding node density and propagation environment. Moreover, it has also been seen that DISPOW is capable of achieving adaptability in line with network changes as a result of dynamic wireless channel variations and node mobility [103].

3.3.1.1 Distributed power management algorithm, DISPOW

As can be seen when reviewing algorithm 1, there is a periodic check carried out between the nodes and their connectivity, with attention also directed towards battery power and interference levels [102].

Algorithm 1 Distributed power management algorithm (DISPOW)[102]

```
DISPOW.Node
define $P_{T_i} = P_{T_{initial}},\ \psi_i\ and\ C\ ”CriticalBatteryLevel”$
Set $P_{T_i} = P_{T_{initial}}, compute\ \psi_i\, and\, set\, timer = \tau_{id}$
if $\psi_i \leq \psi_{i_{min}}$, then DISPOW.LowConnectivity
else
    if $C_i < C_{i_{critical}}$, then DISPOW.CriticalBatteryLevel
    else
        if $\psi_i \leq \psi_{i_{max}}$, then DISPOW.HighConnectivity
            Compute connectivity degree ,$\psi_{DEG_i} = \frac{\psi_i - \psi_{i_{max}}}{\psi_{i_{max}} - \psi_{i_{min}}}$
            if PowerDown_Request received, then
                DISPOW.PowerDown_Request
                if PowerUp_Request received, then
                    DISPOW.PowerUp_Request
                    if suffering from interference, then DISPOW.Interference
                        Sleep until timer expires
                    end if
                end if
            end if
        end if
    end if
end if
```

```
DISPOW.LowConnectivity
if $P_{T_i} = P_{T_{imax}}$, , then calculate $P_{T_i} = P_{T_i} + \Delta P$ and
    set timer $= \tau_{sd}$
else set timer $= \tau_{ld}$
end if
if No Asymmetric link to itself, then
    broadcast PowerUp_Request and set timer $= \tau_{md}$
end if
DISPOW.HighConnectivity
if $P_{T_i} = P_{T_{imax}}$, then calculate $P_{T_i} = P_{T_i} - \Delta P$ and
    set timer $= \tau_{sd}$
else set timer $= \tau_{ld}$
end if
DISPOW.Interference
Broadcast PowerDown_Request
Set TTL and hop count
DISPOW.PowerUp_Request
if $\psi_{DEG_i}$ in high range, then calculate $P_{T_i} = P_{T_i} + \Delta P$ and
    set timer $= \tau_{sd}$
else set timer $= \tau_{ld}$
end if
DISPOW.PowerDown_Request
if $\psi_{DEG_i}$ in high range, then calculate $P_{T_i} = P_{T_i} - \Delta P$ and
    set timer $= \tau_{sd}$
else set timer $= \tau_{ld}$
end if
DISPOW.CriticalBatteryLevel
if $\psi_{DEG_i}$ in high range, then calculate $P_{T_i} = P_{T_i}$-$\Delta P$ and
    set timer $= \tau_{sd}$
else set timer $= \tau_{ld}$
end if
```

3.4 Proposed Protocol

3.4.1 Adaptive Per-Packet Transmission Power Control

Adaptive per-packet transmission power control seeks to ensure a particular SNIR value is sustained. This particular method is concerned with realising the path loss of signal through drawing a comparison between the power that is transmitted, which is in the header of the packet, against the power that is received. The signal power deemed necessary to facilitate reaching each of the neighbours is calculated by each node through packet exchange[116]. In the current work, the DISPOW (transmission power control) algorithm of each packet carrying data, i.e. dumb packets, are adaptively set to the value recognised as necessary to reach the subsequent station outlined on its cognitive map.

3.4.2 Operation of Ad Hoc Cognitive Packet Network with Adaptive Per-Packet Transmission Power Control

In much the same way as other routing protocols, AHCPN conventionally applies a fixed transmission power, which is able to achieve connectivity. Energy sensitivity is attained through utilising those paths that are recognised as having maximum residual energy; this facilitates an increased network lifetime. Adaptive power control schemes could be implemented not only in order to reduc the consumptions of power, but also as a means to increase network capacity. In an effort to validate the per-packet transmission power control performance, changes were made to the AHCPN in order to facilitate its incorporation of transmission power in each packet's header. There has been the addition of a field to the AHCPN packet header; this comprises the packet's transmission power. Importantly, it is the reception power levels available at the link layer that provide this value, with each packet's transmission power recognised as determined by the node and accordingly stamped on the packet.

In the present chapter, the DISPOW algorithm was applied in order to implement an adaptive power control scheme, where adaptive transmission power is used by dumb packets, which is suitable in terms of satisfying the recipient node.A number of different elements inherent in the AHCPN functionality have been changed so as to facilitate adaptive power control. Such changes include the incorporation of a field intto the packet structure, which details the packet's transmission power. All of the nodes transmitting the packet make use of this field with the objective of stamping the transmission power. Importantly, in the case of DP transmissions, the transmission power field is fundamental. Owing to the fact that each DP is transmitted at different power levels, this particular field's information is utilised in order to update the signal's attenuation level.When an ACK packet passes a node, there is an update of the attenuation factor to the node, with dumb packets transmitted at a changed degree of power so as to ensure minimal disruption is felt by the network.

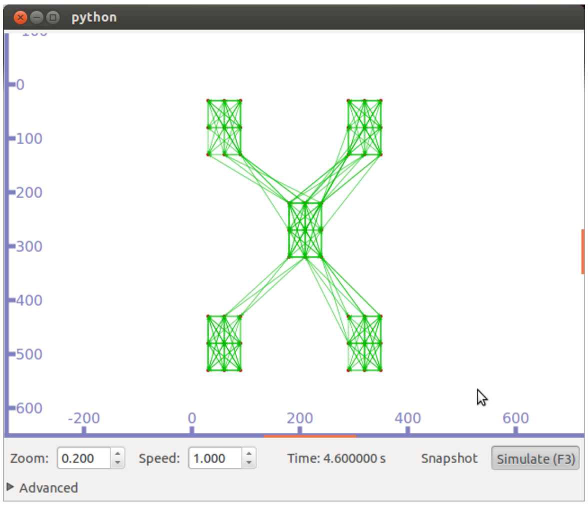
3.5 Simulation and Result

An (AHCPN) was implemented and combined with DISPOW Algorithm by using NS-3.24. The experiments involved carrying out establishment observations and route use in the network. All experiments focused on the network operation for 1000s and transmission power chose adaptively, sort delay = 0.25 ms, long delay is 5 ms, as shown in Table 3.1 .

Table 3.1 **AHCPN Simulaltion Parameters**

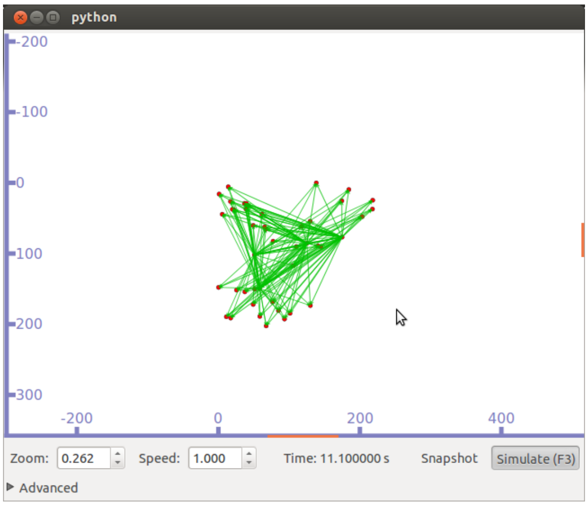
Simulator	**NS-3 version 3.24**
Simulation time	1000 s
Traffic	Constant Bit Rate UDP
Link data rate	IEEE 802.11
Propagation Model	Two Rate Ground
Maximum Transmission Power	0.660 W
Reception Power	0.395 W
Idle Power	0.035 W
Initial Energy	10000 J

A total of 45 nodes according to [9] were implemented for simulation. The results were gathered through the use of the power control algorithm, which are COMPOW and CLUSTERPOW (PLR) [9], power control algorithm (DISPOW) and also without power control algorithm. Notably, the simulation result has been used by Lent et al.,topology [9] and we propose a new topology as highlighted in Figure 3.1. All nodes are recognised as starting with a full battery energy.



Zoom: 0.200 Speed: 1.000 Time: 4.600000 s

(a) Lent et al.,topology[9]

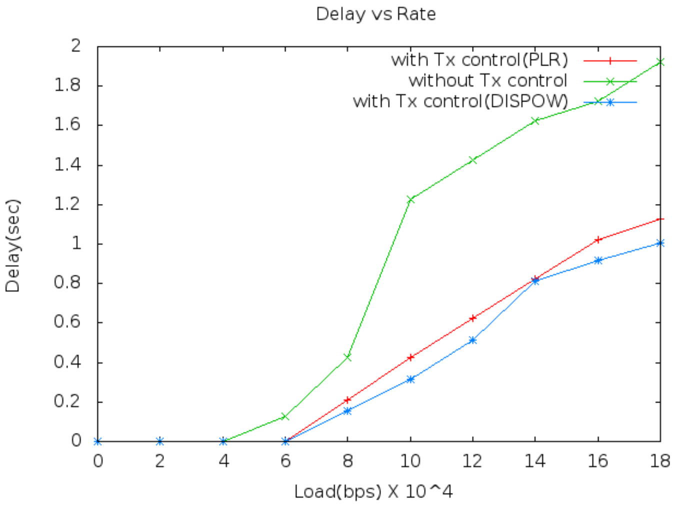


Zoom: 0.262 Speed: 1.000 Time: 11.100000 s

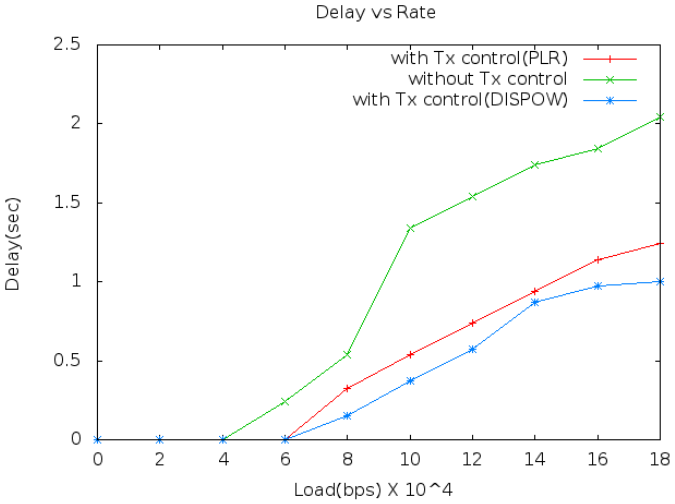
(b) Dynamic Simulation topology

Fig. 3.1 A Simulation topologys

Figure 3.2 shows the relation between the delay of data transmission which is the time of the packet sent minus time of the packet receive and the load of data for three methods. It can be observed that there is sensible transmission delay of TX without control starting at around 4×10^4 bps, whilst in the case of the TX with control (PLR) and TX with control (DISPOW), the sensible transmission delay started around 6×10^4bps. It can be seen in Figure 3.2 that the highest and lowest data transmission delay trends were observed in TX with control (PLR) and TX with control (DISPOW), respectively, whilst TX with control (PLR) fell in-between. It can be seen in the figure that, for a given value of load, the delay in TX without control was seen to be twice as slow as the transmission with TX with control (DISPOW).



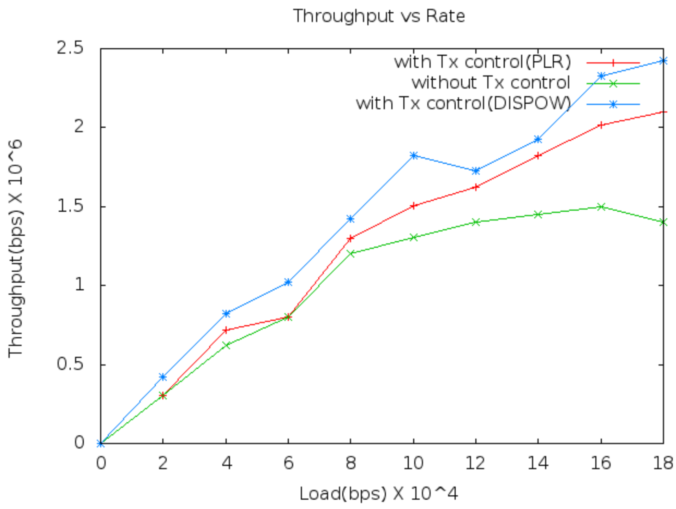
(a) Lent et al.,topology [9] Delay vs. Rate



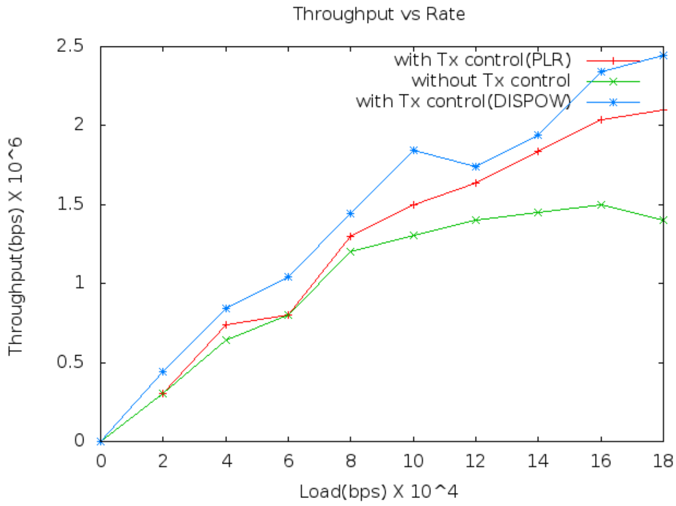
(b) Dynamic topology Delay vs. Rate

Fig. 3.2 Delay vs. Rate

Figure 3.3 presents the comparison between the number of throughput (for all DPs in the system) for a varied number of loads. All of the methods experience the same trends. From Figure 3.3, it can be observed that there has been a slight increase in the number of throughputs for methods with TX control (PLR), without TX control, and with TX control (DISPOW).



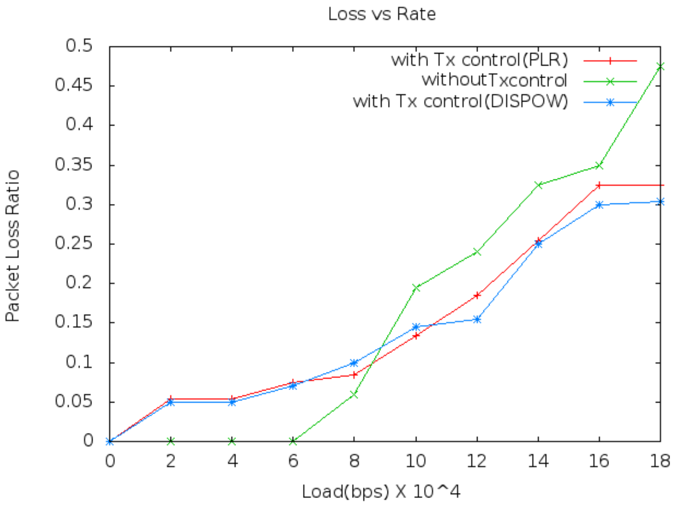
(a) Lent et al.,topology [9] Throughput vs. Rate



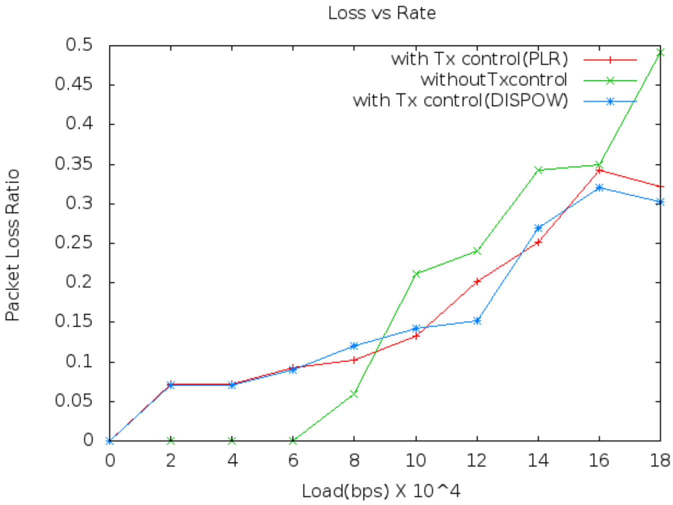
(b) Dynamic topology Throughput vs. Rate

Fig. 3.3 Throughput vs. Rate

Figure 3.4 describes the Relationships between the packet loss ratio against load of data for three methods. As can be seen in the graph, there is sensible packet loss from nearby zero to around 6×10^4 bps for normal transmission (TX without control). The packet loss ratio starts increasing significantly when the transmission load is larger than 6×10^4. On the other hand, the PLR and DISPOW algorithm experienced nearby zero packet losses at zero data load. Subsequently, packet losses rose gradually until reaching around 0.3 for TX with control (DISPOW) and 0.325 for TX with control (PLR).



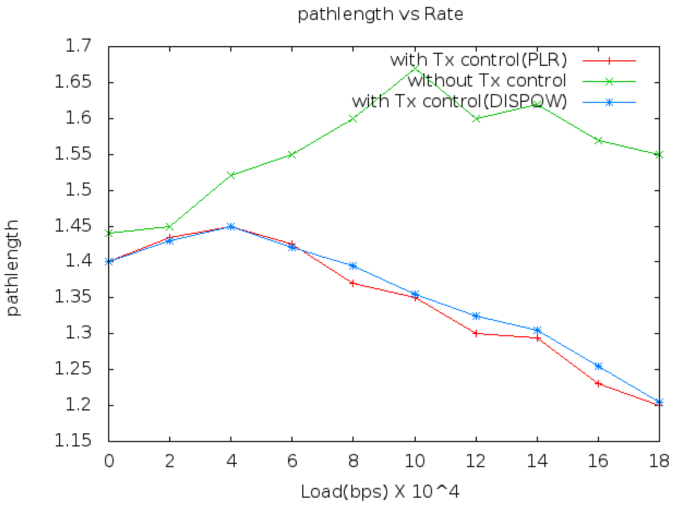
(a) Lent et al.,topology [9] Packet loss vs. Rate



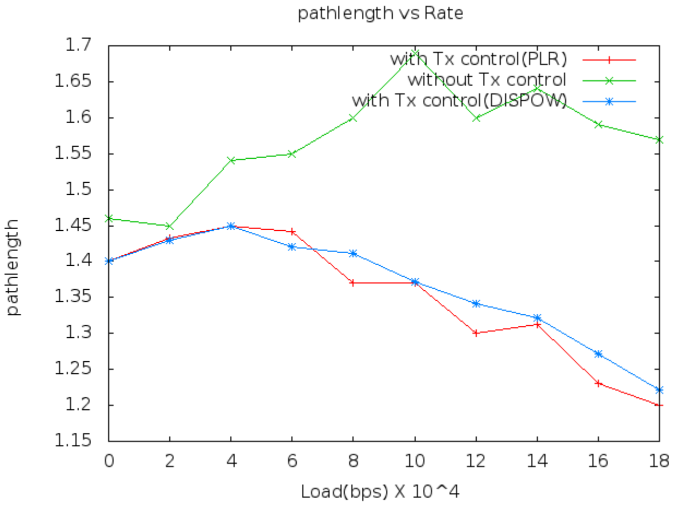
(b) Dynamic topology Packet loss vs. Rate

Fig. 3.4 Packets loss vs. Rate

Figure 3.5 shows the Relationships between the path lengths which is specify the number of hopes is between 1 to 2 , against the load of data for the three methods. It can be seen that both transmission with PLR and DISPOW Have almost the same trends, whilst transmission without control contradicts those methods.



(a) Lent et al.,topology [9] path length vs. Rate

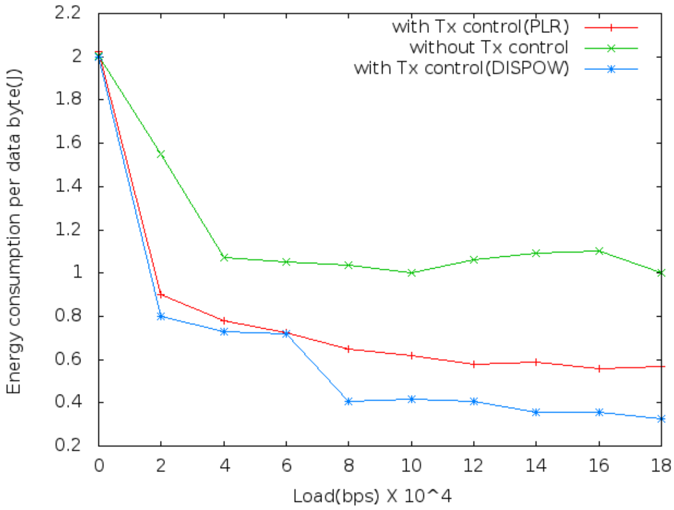


(b) Dynamic topology path length vs. Rate

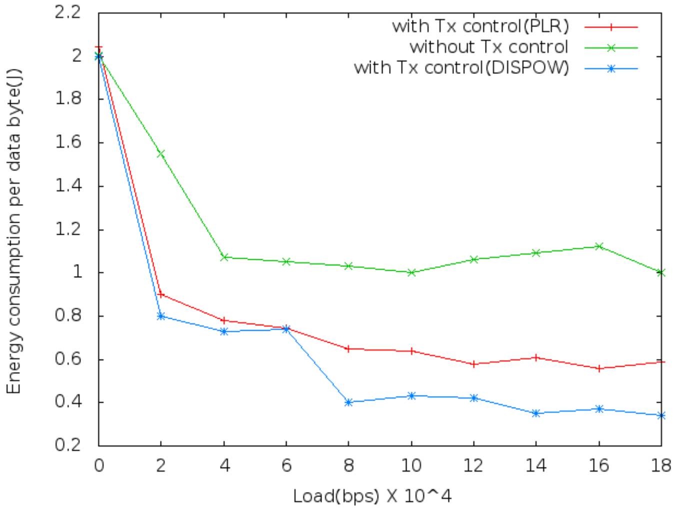
Fig. 3.5 Path length vs. Rate

Figure 3.6 illustrates the amount of energy consumed per data byte as the load of the network increases. When the number of loads is near to zero, all of the algorithms have two energies consumed. In the transmission without control, this energy dropped sharply until around 1.1 J, when the load is seen to be 40 Mbps. Then, it remained stable at 1.1 J until the end of the simulation. In the transmission with control, the energy consumed went down to 0.9 J for PLR and 0.8 J for DISPOW at 20 Mbps. Later, both the energy decreased slowly at approximately 0.6J for PLR and 0.3 J for

DISPOW. In short, transmission without control has the highest energy consumed compared to transmission with control.



(a) Lent et al.,topology [9] Energy vs. Rate



(b) Dynamic topology Energy vs. Rate

Fig. 3.6 Energy vs. Rate

3.6 Summary

We have presented AHCPNs with DISPOW power control scheme, which seeks to decrease power utilisation at the nodes. Nodes were enhanced through decreasing their transmission power, meaning the nodes' energy availability does not notably decline. The end result shows that the packets flow through the network at a level of power deemed suitable in terms of establishing communication without causing neighbouring nodes to be disrupted in any way. The packets will also opt for flows through nodes with longer battery lifetime and with a greater probability when compared with those nodes offering a shorter remaining lifetime.

The value of power control algorithms in the AHCPNs protocol have been demonstrated, which are as follows: the capacity to dynamically identify neighbours and routes; the ability to identify and maintain routes without requiring significant broadcasts; the distribution of network traffic in order to extend the nodes' overall battery lifetime; and maintaining a sound performance when compared with higher energy consumption rates and broadcast-centred approaches.

Chapter 4

LINK EXPIRATION TIME AWARE DISTRIBUTED POWER MANAGEMENT ALGORITHM, LETPOW

4.1 Introduction

A distributed power control approach is an important part in Mobile Ad hoc Networks that provides better network connectivity to achieve the good performance. The conventional approaches deal with this issue and that are classified into five main approaches: Node-Degree Constrained based, Graph Theory based, Game Theory based, Location Information based and Multi-Parameter Optimization based. One of the existing approach [103] proposed adaptive distributed power management [DISPOW] algorithm based on the Multi-Parameter Optimization approach. This approach manages the transmit power of nodes through wireless ad hoc network. The proposed tailored stable network topology builds in distributed manner that preserves network connectivity and minimize the interference. Mutual Exclusion is one of the best solutions for resource sharing on distributed network. In [117] authors presented a new fully distributed token based mutual exclusion scheme for clustered MANETs which evaluate the performance of power optimization. Raymond's algorithm is proposed for executing user jobs using First-in, first-out (FIFO) queuing. The problem of proposed Raymond's algorithm is unfair and not applicable for large scale distributed systems. Interference aware topology control in MANET is discussed in [102]. This is about Adaptive Distributed Power Management scheme that preserves network connectivity and reduce the interference adaptively in dynamic environment. If the SINR value is greater than the threshold, the noise interference between nodes attains low.

Energy conservation is an essential factor in DISPOW which focuses on [118] for location based topology control with sleep scheduling in MANETs. As a part of power management scheme, traffic conditions are considered and monitored continuously. Based on the traffic conditions, a node put into sleep state. In this chapter, more number of nodes are put into sleep state because a node with less energy and does not participate with transmission is goes to sleep state, and a node with more congestion is also goes to sleep state. Due to this effect, packet transmission rate is low when compared to the conventional schemes. To investigate the efficiency of nodes transmission power, a novel distributed transmission power control protocol was proposed in [119]. The proposed protocol called "Distributed Power Level (DPL) for multi-channel ad hoc networks that works without requiring clock synchronization. Two kinds of transmission modes are introduced in DPL: symmetrical mode and asymmetrical mode. In symmetrical mode, for selected channel the same power level is assigned and on other hand asymmetrical mode, the selected channel uses lower/equal power level for transmission. Typical MST based topology control schemes were introduced to control the network topology that used in wireless multi-hop networks. Due to the flexibility, the system leads to poor performance in terms of network capacity and transmission power [120]. Interference limited ad hoc network is proposed in the High SINR regime that scope is to optimize the network utility and improve the energy efficiency [121]. To this end, various strategies were invoked such as backpressure routing, interference, power cost, power control driven by backlog, local queue lengths, backpressure routing. In order to make the strong foundation of topology control and routing, in [122] proposed cross layer distributed algorithm for considering and overcomes the problems of interference with proposing two constraints such as delay constraint and interference constraint. Through this algorithm unstable links are removed from the network topology. This leads to less packet delivery ratio and high routing overhead.

In this chapter, we propose a new power control algorithm for Mobile Ad hoc Network (MANET). The suggested algorithm is a Link Expiration Time Aware Distributed Power management algorithm, (LETPOW). Our main aim is to periodically check Connectivity, Transmission power, Interference level, Routing overhead and Node Mobility in MANET. We deliver a modified time-varying signal-to-interference-noise ratio (SINR) formula. The proposed algorithm considers additional parameters such as link expiration time, continuous time interval and the total number of scheduled slots compared to the existing Distributed Power management algorithm (DISPOW) in distributing the power.

4.2 Link Expiration time Aware Distributed Power management algorithm, LETPOW.

4.2.1 Problem definition

$P_{T_i}(t)$ and $\psi_{\boldsymbol{i}}(\boldsymbol{t})$ may be defined as the transmitting power and connectivity of node *i* at time *t* in the network of *N* nodes in an area *A*, then we need to select [102]

$$P_{T_i}(t)\ \forall\ node\ \boldsymbol{i}\ in\{1,2,...,N\} \tag{4.1}$$

1. There is a need for the node to have at least minimum connectivity with an acceptable number of neighbours facilitating a bi-directional link at any given time *t*.

$$\psi_i(t) \geq \psi_{i_{min}}(t)\ \ \forall\ \ node\ \ i\ in\ \{1,2,...,N\} \tag{4.2}$$

2. In order to ensure a packet from node j to node i can be suitably identified, signal to interference and noise ratio at the latter node needs to be larger than a threshold.

   SNR are calculated based on the quality of wireless link should be process with time t.

$$SINR_t^l = \frac{h_l p_t^l}{\sigma W + \sum_{l' \in Ll' \neq l} h(TX_l, RX_l) p_t^{l'}} (\forall\ l \in L, t \in \Gamma) \tag{4.3}$$

where h_l is propagation gain of link , p_t^l continuous time interval, σ thermal noise, W is link capacity , L refers to set of nodes causing interference and Γ represents total number of scheduled time slots

Furthermore, upon the node transmitting, this should not be at such a high level that it causes interference across other neighbouring nodes. In particular, there is a need to ensure the total noise power P_{N_i} in the node ***i*** is reduced.

$$\min P_{n_i} \quad \forall node\, i\; in \{1,2,...,N\}\; where\, P_{N_i} = P_0 + \sum_{\substack{K\in N\\ k\neq j}} P_{ki}(t) \tag{4.4}$$

In addition, should a node be recognised as displaying high node connectivity, it might then be positioned to lower its transmitting power whilst still maintaining acceptable ψ. "Let ψ_{imax} be the maximum number of neighbors allowed, i.e.". textmodeThe upper acceptable connectivity threshold then should be set, which allows the benefit of decreasing inter-node interference in the network.

$$\psi_i(t) \leq \psi_{i_{max}}(t) \quad \forall node\, i\; in \{1,2,...,N\} \tag{4.5}$$

3. For node i, the P_{T_i} should exceed the minimum power level, $P_{T_{imin}}$, although there is a need to ensure it is below the maximum power level. Importantly, $P_{T_{imax}}$, needs to be defined in line with node power and network specifications.

$$P_{T_{imin}} \leq P_{T_i}(t) \leq P_{T_{imax}} \quad \forall node\; i\, in\; \{1,2,...,N\} \tag{4.6}$$

4. The node's overall battery capacity, *C(t)*, also needs to be conserved through the use of the algorithm, which is a critical design element needing to be incorporated within mobile ad-hoc networks. Importantly, nodes can increase their P_T only when their C is greater than the critical battery power level $C_{critical}$.

$$C_i(t) \geq C_{i_{critical}} \quad \forall \;\; node \;\; i \;\; in \;\; \{1,2,...,N\} \tag{4.7}$$

4.2.2 Relationships of Node Connectivity with Node Density, Transmit Power and Physical Network Environment

The dependency of node connectivity ψ on node density ρ and physical network environment with path loss exponent η and the in which a node is positioned to satisfy particular P_T through making adjustments to its transmitting power P_T is discussed in this section. Importantly, an appropriate algorithm parameter range is presented through a sensitivity analysis. If we were to choose node *i* as a reference node, the wireless channel propagation model can be modelled with the long distance path loss and fading propagation model. The rationale behind such selection can be seen in [101], where the propagation loss at the receiver d meter away from node *i*, when making the assumption of the presence of a unit reference distance d_o as delivered by the following [102]:

$$\begin{aligned} P_L &= P_L(d_o) \times d^{\eta} \times L_{Fading}, \\ P_L &= P_L(d_o) + 10\,\eta\,\log(d) + L_{Fading}. \end{aligned} \tag{4.8}$$

where L_{fading} may be recognised as fading loss as a direct result of shadowing and rayleigh fading effects, whilst η is the propagation path loss exponent and $P_L(d_o)$ is regarded as the reference path loss at d_o. In order to achieve a correct reception of packet, P_{T_i} needs to be adequate in line with overcoming any degree of propagation loss whilst also satisfying receiver sensitivity P_{rs}. It is important to acknowledge that, in line with the 802.11 standard, in this chapter, a link may be recognised as good or acceptable should the signal power in the receiving node be seen to be larger than the P_{rs} of –95 dBm. Career sense threshold effect in the case of topology control algorithms undergo examination in [123]. Subsequently, from equation (4.8), the following can be established:

$$P_{T_i}dB \geq P_{rs}dB + P_L(do) + 10\,\eta\,\log(d) + L_{Fading} \tag{4.9}$$

For the sake of simplicity, the fading loss in equation (4.9) will be disregarded, with the effects of fading channel on topology control algorithms presented in [102] from an analytical perspective. Through the simplification of equation (4.9), the following is achieved:

$$
\begin{aligned}
&P_T \geq P_r + P_L(do) + 10\,\eta\ \log(d), \\
&P_T \geq P_r \times P_L(do) \times d^{\eta}, \\
&d^{\eta} \leq \frac{P_T}{P_r \times P_L(do)} = P_T \times K = P_T(P_r \times P_L(d))^{-1}, \\
&d \leq \sqrt[\eta]{kP_{T_i}} \qquad (4.10)
\end{aligned}
$$

where constant $k = (P_{rs} \times P_L(do))^{-1}$.

Accordingly, if a random node l is to successfully receive the packet from node i, notably when transmitting with an omnidirectional antenna, node l needs to be present within node i's coverage area, which is recognised by a radius circle d, as presented through (4.10).

If node density, ρ, be acknowledged as the number of nodes in a unit square area, then the number of uni-directional neighbour of node i, specifically within its area of coverage, can be established through the following (4.11):

Total number of nodes area of circle = $\pi r^2 = \pi d^2$

$$
\begin{aligned}
\textbf{neighbour} &= \left[\pi(k \times P)^{\frac{2}{\eta}}\right] \times \rho - 1 \\
\psi_i &= \pi\rho(kP_{T_i})^{\frac{2}{\eta}} - 1 \qquad (4.11)
\end{aligned}
$$

Such dependency of the number of neighbour a node on the propagation environment.

Lower Bound:

$$\begin{aligned}
&\psi i+1 \geq \pi\rho(kp_T)^{\frac{2}{\eta}}\\
&\frac{\psi i+1}{\pi\rho} \geq (kp_T)^{\frac{2}{\eta}}\\
&(\frac{\psi i+1}{\pi\rho})^{\frac{2}{\eta}} \geq kP_T\\
&P_T \geq \frac{(\frac{\psi i+1}{\pi\rho})^{\frac{2}{\eta}}}{K}\\
&P_{T_i} \geq \frac{1}{k}(\frac{\psi_{i_{min}}+1}{\pi\rho})^{\frac{\eta}{2}}
\end{aligned} \tag{4.12}$$

Assuming node i enhances its P_{T_i} by an increment, ΔP in an attempt to establish links with other nodes not its neighbour within the network. Comparably, there is also the ability of a node to decrease its overall P_{T_i} with ΔP potentially losing links to various neighbours, whilst nonetheless continuing to maintain minimum connectivity, ψ_{min}. The subsequent adjustment in ψ_i as a result of such updates in power levels may be assessed in line with equation (4.11) and equation (4.13).

$$\Delta\psi_i = \pi\rho k^{\frac{2}{\eta}}\left[(P_{T_i} \pm \Delta P)^{\frac{2}{\eta}} - (P_{T_i})^{\frac{2}{\eta}}\right] \tag{4.13}$$

LETPOW maintains the total noise floor below a threshold, Γ inf meaning that the transmission node i is not able to cause nearby nodes to be overwhelmed. When simplifying from (4.4) and (4.8), (4.14) is achieved:

$$P_T dB \leq \Gamma_{inf} dB + 10\,\eta\ \log(d) + P_L(do) + P_o \tag{4.14}$$

4.2.3 The Proposed Algorithm, LETPOW

Our main aim is to periodically check Connectivity (ψ), Transmission power (T), battery power (C),Interference level (I), Routing overhead (R) and Node Mobility (M) in the network of N nodes at time t. Formula at time (t) has been updated. the signal-to-interference-plus-noise ratio (SINR) should be high for the better signal strength and quality of transmission. In existing algorithm which is Distributed Power management algorithm (DISPOW), they consider thermal noise, received power level and interference. In preposed algorithm we added few more parameters such as propagation link, continuous time interval and total number of scheduled slots. So our new algorithm surely improves quality of transmission and signal strength.

Algorithm 2 LETADISPOW

```
LETADISPOW.Node
Set $P_{T_i} = P_{T_{initial}} = 1000J, compute\ \psi_i\ which\ is\ adaptively\ and\ set\ timer = \tau_{id}$ ,Soft state_Timer=T$i$, Link expiration time=l$i$,Power level (E$ij$), node transmit fixed rate =$R$,energy = $\varepsilon$ and node identifier = n$id$
if $\psi_i \leq \psi_{i_{min}}$ & $l_{i_{min}}$ then LETPOW.LowConnectivity
else
    if $C_i < C_{i_{critical}}$ & $l_{i_{min}}$ then LETPOW.CriticalBatteryLevel
    else
        if $\psi_i \leq \psi_{i_{max}}$ & $l_{i_{max}}$ then LETPOW.HighConnectivity
            Compute connectivity degree ,$\psi_{DEG_i} = \frac{\psi_i - \psi_{i_{max}}}{\psi_{i_{max}} - \psi_{i_{min}}} + \frac{l_i - l_{i_{min}}}{l_{i_{max}} - l_{i_{min}}} + n_{id}$
            Compute link expiration time factor $l_{FAC_i} = \frac{\varepsilon_i}{\varepsilon_r + N_o}$
            Compute node mobility factor $m_{FAC_i} = (n_i - n_j) \times (1/\varepsilon)\ where\ \varepsilon > 0$
            if PowerDown_Request received, then
                DISPOW.PowerDown_Request
                if PowerUp_Request received, then
                    DISPOW.PowerUp_Request
                    if If PowerOff_Request received, then
                        DISPOW.PowerOff_Request
                        if suffering from interference, then LETPOW.Interference
                            Sleep until timer expires
                        end if
                    end if
                end if
            end if
        end if
    end if
end if
```

```
LETPOW.LowConnectivity
if $P_{T_i} < P_{T_{imax}}$, then calculate $P_{T_i} = P_{T_i} + \Delta P$ and
    set timer = $\tau_{sd}$
else
    if (i>j), then $(E_i\, and\, E_j satisfy)$
        $\log_2(1 + \frac{E_i}{E_j + N_0}) \geq R$
    else
        if (j>0), then $(E_j\, satisfy)$
            $\log_2(1 + \frac{E_j}{N_0}) \geq R$
        else set timer = $\tau_{ld}$
        end if
    end if
end if
if No Asymmetric link to itself, then
    broadcast PowerUp_Request and set timer = $\tau_{md}$
end if
LETPOW.HighConnectivity
if $P_{T_i} > P_{T_{imax}}$, then calculate $P_{T_i} = P_{T_i} - \Delta P$ and
    set timer = $\tau_{sd}$
else
    if (i>j), then $(E_i\, and\, E_j satisfy)$
        $\log_2(1 + \frac{E_i}{E_j + N_0}) \geq R$
    else
        if (j>0), then $(E_j\, satisfy)$
            $\log_2(1 + \frac{E_j}{N_0}) \geq R$
        else set timer = $\tau_{ld}$
        end if
    end if
end if
LETPOW.Interference
if (i>j), then $(E_i\, and\, E_j satisfy)$
    $\log_2(1 + \frac{E_i}{E_j + N_0}) \geq R$
else
    if (j>0), then $(E_j\, satisfy)$
        $\log_2(1 + \frac{E_j}{N_0}) \geq R$
    end if
end if
Set TTL and Hop Count
LETPOW.PowerUp_Request
if $\psi_{DEG_i}$ in lower range,$l_{FAC_i}$,in minimum and $m_{FAC_i}$with minimum value , then calculate $P_{T_i} = P_{T_i} + \Delta P$ and
    set timer = $\tau_{sd}$
else set timer = $\tau_{ld}$
end if
```

```
LETPOW.PowerDown_Request
if $\psi_{DEG_i}$ in high range,$l_{FAC_i}$,in minimum and $m_{FAC_i}$with minimum value, then calculate $P_{T_i} = P_{T_i} - \Delta P$ and
    set timer = $\tau_{sd}$
else set timer = $\tau_{ld}$
end if
LETPOW.PowerOff_Request
if $\psi_{DEG_i}$ in low range,$l_{FAC_i}$,in minimum and $m_{FAC_i}$with minimum value, then calculate $P_{T_i} = P_{T_i} - \Delta P$ and
    set timer = $\tau_{sd}$
else set timer = $\tau_{ld}$
end if
LETPOW.CriticalBatteryLevel
if $\psi_{DEG_i}$ in high range,$l_{FAC_i}$,in minimum and $m_{FAC_i}$with minimum value, then calculate $P_{T_i} = P_{T_i}$-$\Delta P$ and
    set timer = $\tau_{sd}$
else set timer = $\tau_{ld}$
end if
```

4.3 Simulation Results

The result in this chapter will divide into two section, section 4.3.1 show the compare of two different algorithms which is DISPW and LETPOW to implement Link Expiration time Aware Distributed Power management algorithm (LETPOW) and section 4.3.2 show implemented and combine AHCPN with LETPOW algorithm.

4.3.1 Link Expiration time Aware Distributed Power management algorithm, LETPOW.

In this section we compare the two different methods which is DISPOW and LETPOW algorithms:

Figure 4.1.a Average node power of the proposed protocol compared with DISPOW. This figure compares the performance of the proposed protocol with our implementation of the DISPOW protocol applying 100 random network topologies. Our protocol aims to operate just adequate number of nodes at a common power-level (the smallest power-level at which a strong network connectivity is guaranteed). Where transmit power according to our algorithm is limited to be below P_{Max}.

Figure 4.1.b Noise floor of the proposed algorithm compared with that of DISPOW algorithm. The average thermal noise with proposed algorithm is lower than that with DISPOW as seen in figure 4.1.b. Where transmit power required to connect isolated nodes can cause high level of node interference in a denser part of the network. Since our algorithm requires less transmit power this inherently implies a decrease in node interference. Also, in a higher path-loss attenuating environment the effect is obvious since we have limited transmit. It is worth noting that higher noise floor results in higher transmit power level and consequently more node interference.

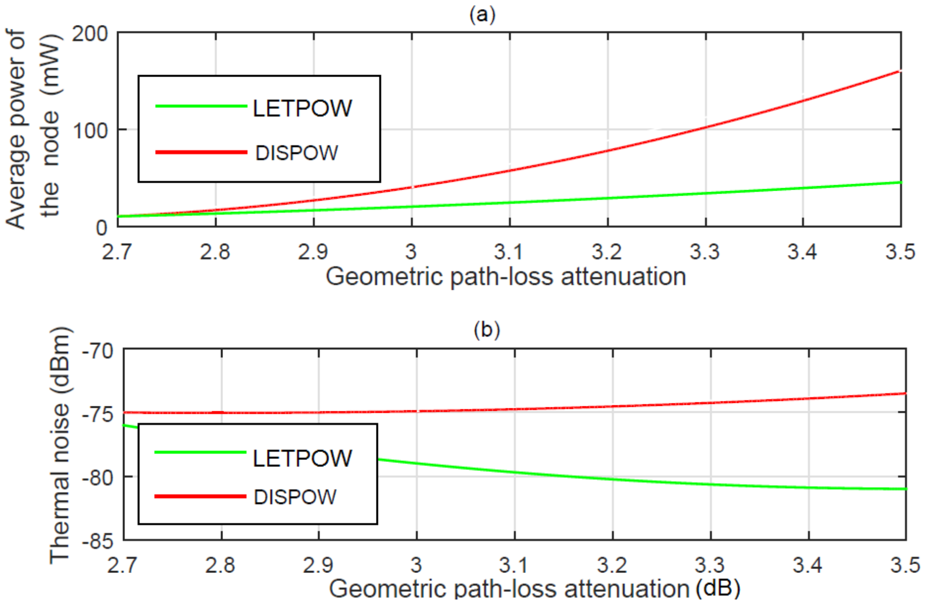


Fig. 4.1 Average node power & Noise floor of the proposed algorithm compared with that of DISPOW.

The Figure 4.2 evaluating the performance of the proposed protocol over 100 random topologies of the network, from Figure 4.2.a, it is clear that proposed algorithm outperform the DISPOW over different transmit power. From Figure 4.2.b, it is clear that the average number of links decreases with increasing attenuating environment (path-loss), the urban area between 2.7 to 3.5. The the proposed algorithm outperforms the DISPOW algorithm. Where power distribution analysis shows that in low attenuating propagation environment most of the available nodes have transmit power less than the average power.

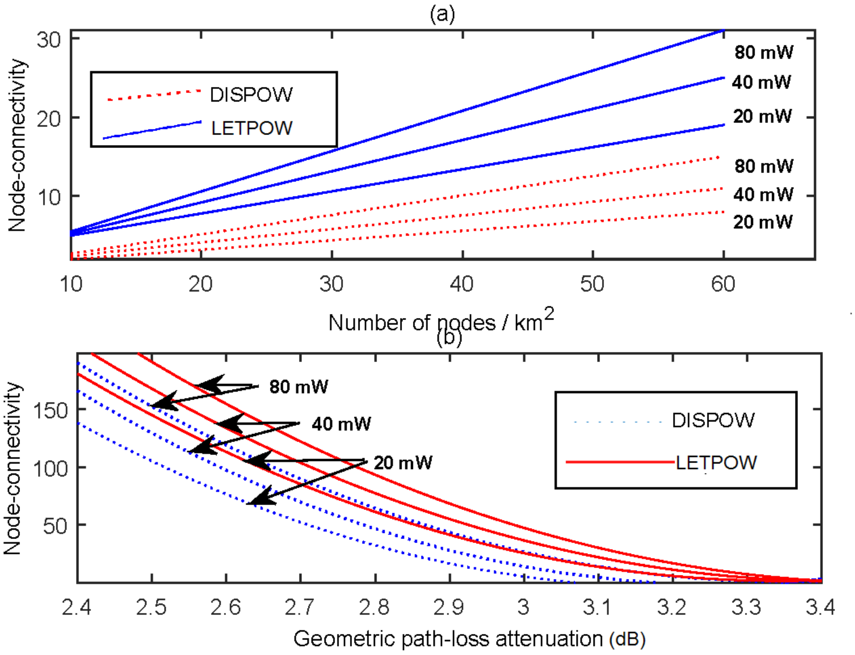


Fig. 4.2 Effect in node connectivity by changing its transmit power in different propagation environments.

Figure 4.3.a Transmit Power Impact on node connectivity for different propagation environments This figure shows average node power for different propagation environment over 100 random network topologies. The average connectivity increases as we increase transmit power. Results of power distribution shows that most of the nodes in low attenuating propagation environment have transmit power less than the average power. A node can keep a certain connectivity by increasing transmit power according to the propagation environment, where in a suburban environment, characterised by path loss exponent of 2.9, a node can adjust its power higher than 0.02 watt to maintain its connectivity at 30%.

Figure 4.3.b depicts the impact of minimum number of links assumed in the protocol, that the average Node power increases with increasing attenuating environment. The average power also increases as minimum connectivity increases. Where cases v=2.9, v=3.0 and v=3.4 are for minimum connectivity of 1,2 and 4, respectively.

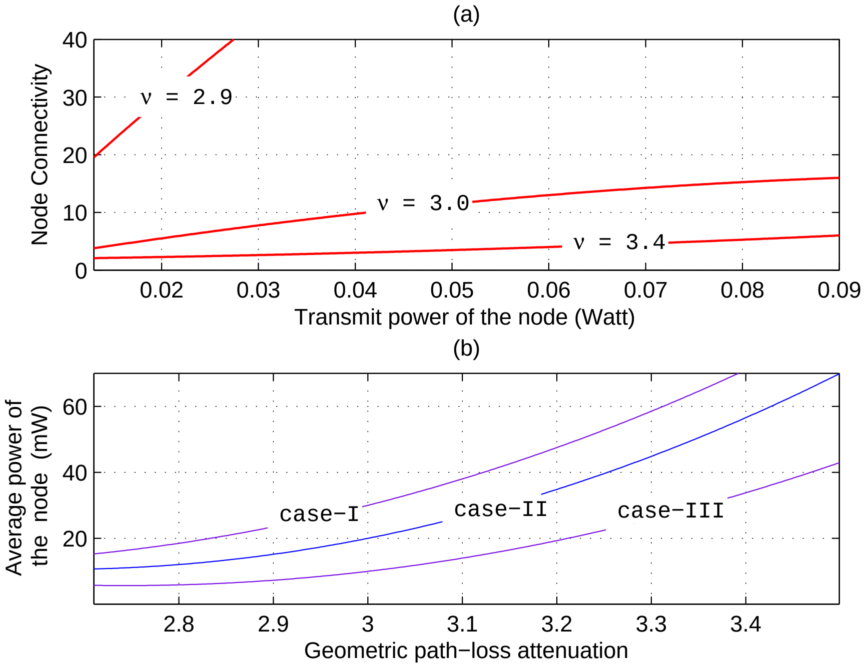


Fig. 4.3 Path loss exponent (propagation model) impact on the node connectivity.

4.3.2 AHCPN with LETPOW Algorithm

An AHCPN was implemented and combined with LETPOW algorithm by using NS-3.24. The experiments involved carrying out establishment observations and route use in the network. All experiments focused on the network operation for 1000s, as shown in Table 4.1 .

Table 4.1 **AHCPN Simulaltion Parameters**

Simulator	**NS-3 version 3.24**
Simulation time	1000 s
Traffic	Constant Bit Rate UDP
Link data rate	IEEE 802.11
Propagation Model	Two Rate Ground
Maximum Transmission Power	0.660 W
Reception Power	0.395 W
Idle Power	0.035 W
Initial Energy	10000 J

Totally, there are 45 nodes in this simulation, and we run the simulations according to per-packet power control algorithm in section 3.4 as the transmission with and without power control algorithms. In transmission with power control, three methods has been applied: Lent et al.,topology [9] method, DISPOW, and LETPOW. The last method is the proposed approach as highlighted in Figure 4.4. All nodes are recognised as starting with a full battery energy.

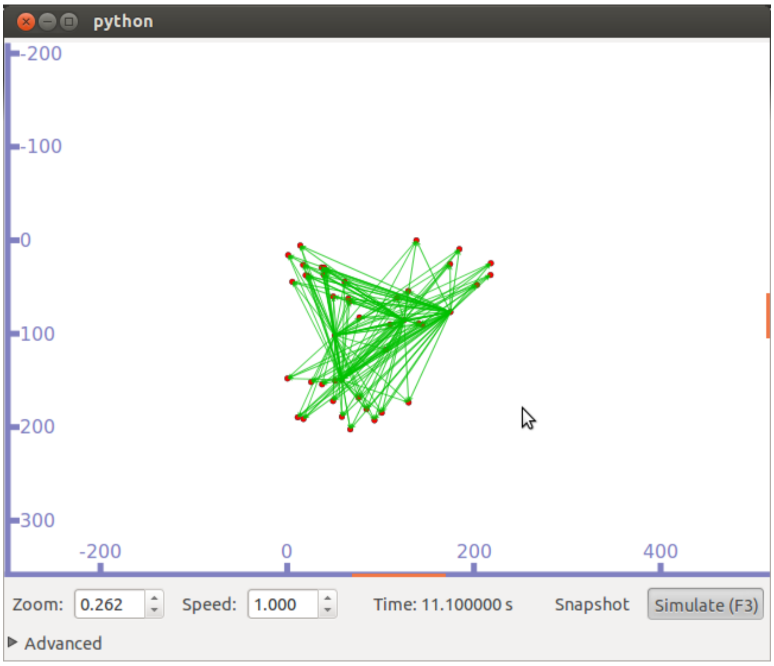


Fig. 4.4 LETPOW Simulation topology.

Figure 4.5 shows the relation between the delay of data transmission and the load of data for four methods. It can be observed that there is sensible transmission delay of TX without control starting at around 4×10^4 bps , whilst in the case of the TX with control (PLR), TX with control (DISPOW) and TX with control (LETPOW), the sensible transmission delay started around 6×10^4 bps. It can be seen in Figure 4.5 that the highest and lowest data transmission delay trends were observed in TX with control (PLR) and TX with control (LETPOW), respectively, whilst without TX control and with Tx control (DISPOW) fell in-between. It can be seen in the figure that, for a given value of load, the delay in TX without control was seen to be (2.25) TX with control (LETPOW) as slightly slow as the transmission with TX with control (LETPOW).

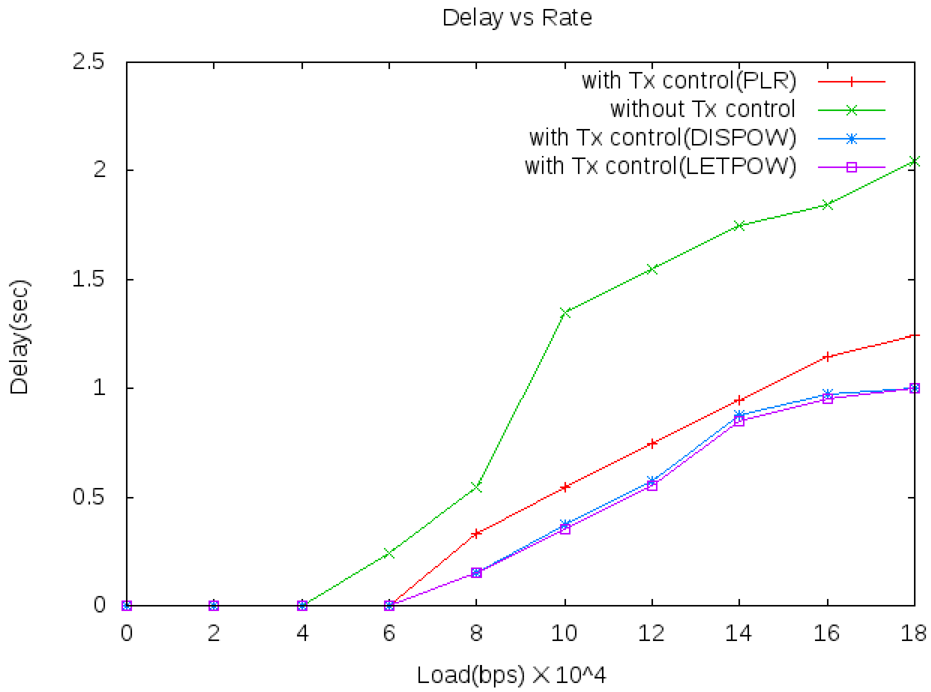


Fig. 4.5 LETPOW method Delay vs. Rate.

Figure 4.6 presents the comparison between the number of throughput for a varied number of loads. All of the methods experience the same trends. From Figure 4.6, it can be observed that there has been a slight increase in the number of throughputs for methods TX with control (PLR), TX without control, TX with control (DISPOW) and TX with control (LETPOW). Specifically TX with control (DISPOW) and TX with control (LETPOW) have the same pattern for case of load, but the load is 14×10^4 slightly enhance for LETPOW algorithm.

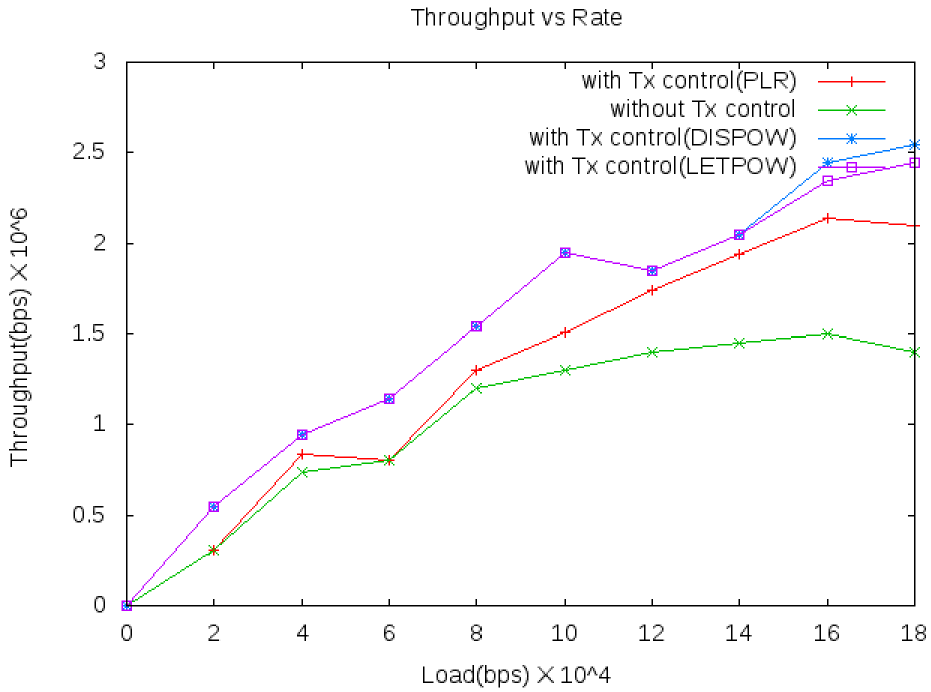


Fig. 4.6 LETPOW method Throughput vs. Rate.

Figure 4.7 describes the Relationships between the packet loss ratio against load of data for four methods. As can be seen in the graph, there is sensible packet loss from nearby zero to around 6×10^4 bps for normal transmission (TX without control). The packet loss ratio starts increasing significantly when the transmission load is larger than 6×10^4. On the other hand, the PLR , DISPOW and LETPOW algorithm experienced nearby zero packet losses at zero data load. Subsequently, packet losses rose gradually until reaching around 0.4 for TX with control (DISPOW) , 0.425 for TX with control (PLR) and 0.325 for TX with control (LETPOW).

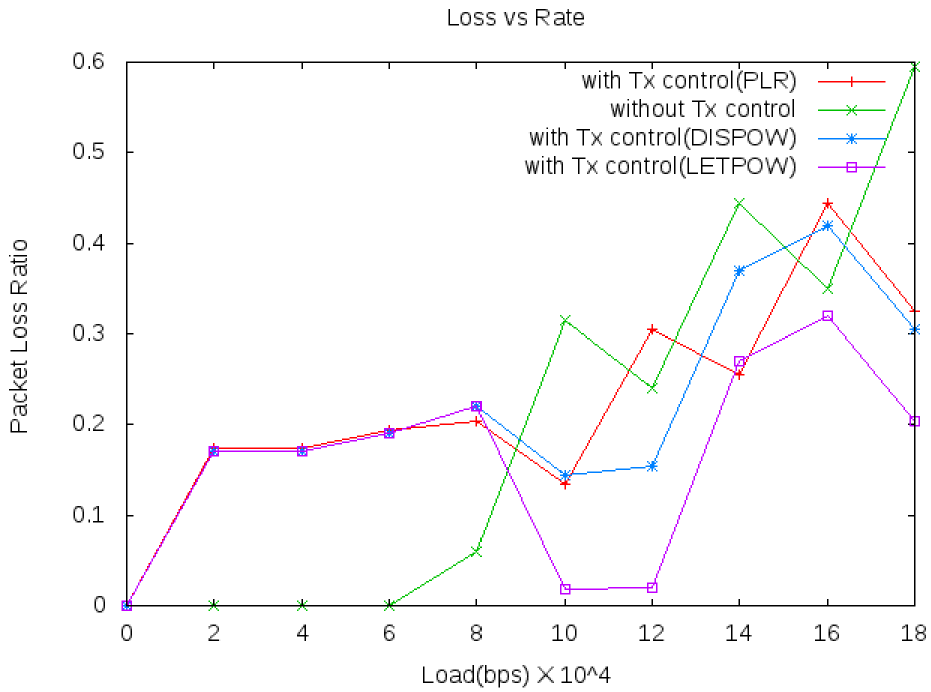


Fig. 4.7 LETPOW method Packet loss vs. Rate.

Figure 4.8 shows the Relationships between the path lengths against the load of data for the four methods. It can be seen that both transmission with PLR ,DISPOW and LETPOW Have almost the same trends until load value around 6×10^4 and the trends different beyond this vale, but the LETPOW algorithm has better performance , whilst transmission without control contradicts those methods.

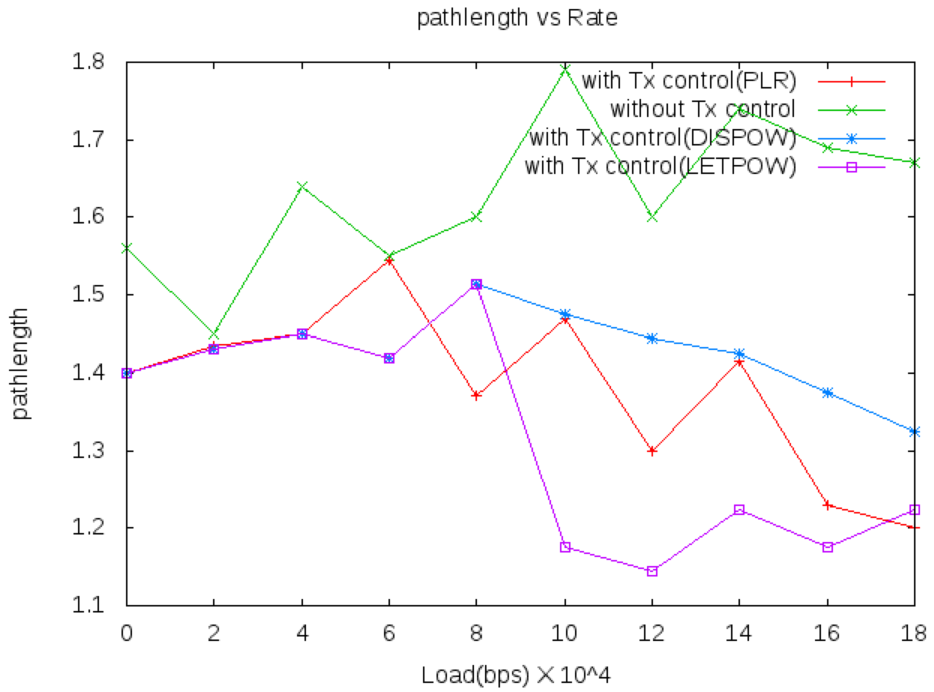


Fig. 4.8 LETPOW method path length vs. Rate.

Figure 4.9 illustrates the amount of energy consumed per data byte as the load of the network increases. When the number of loads is near to zero, all of the algorithms have two energies consumed. In the transmission without control, this energy dropped sharply until around 1.1 J, when the load is seen to be 40 Mbps. Then, it remained stable at 1.1 J until the end of the simulation. In the transmission with control, the energy consumed went down to 0.9 J for PLR and 0.8 J for DISPOW and LETPOW at 20 Mbps. Later, both the energy decreased slowly at approximately 0.6J for PLR and 0.3 J for DISPOW and LETPOW. Specifically TX with control (DISPOW) and TX with control (LETPOW) have the same pattern for case of energy consumption. In short, transmission without control has the highest energy consumed compared to transmission with control.

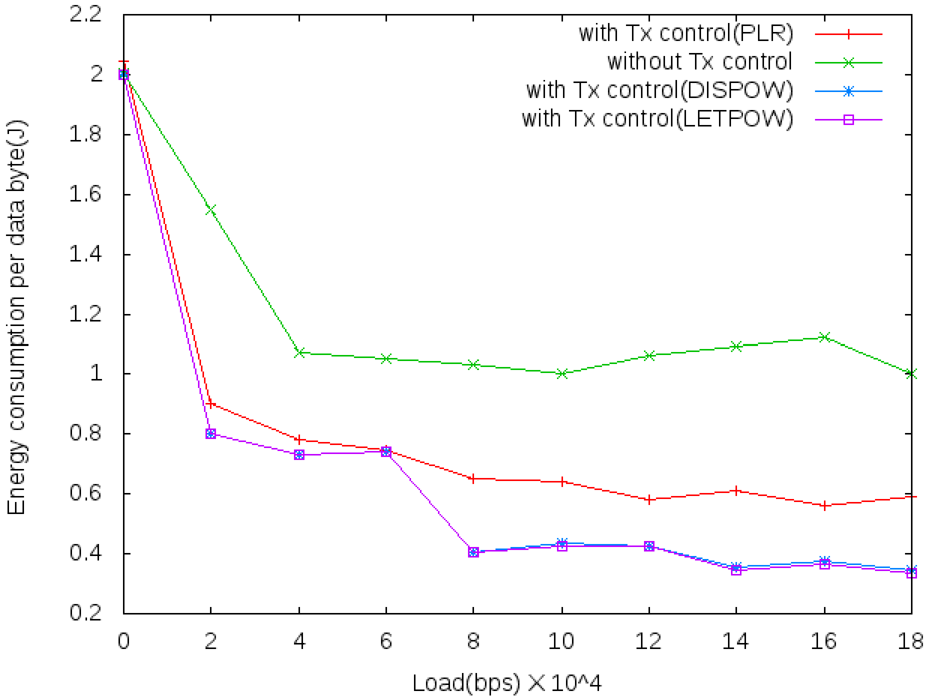


Fig. 4.9 LETPOW method Energy vs. Rate.

4.4 Summary

We have presented Update DISPOW algorithm, namely LETPOW ,furthermore we apply AHCPNs with LETPOW power control scheme and compare with Lent et al., [9] method, which seeks to decrease power utilisation at the nodes. Nodes were enhanced through decreasing their transmission power, meaning the nodes energy availability does not notably decline. The end result shows update DISPOW and LETPOW algorithms have almost better performance, specifically, in this chapter we deliver new power control algorithm (LETPOW) which focus on Link Expiration Time. Our main aim is to periodically check Connectivity, Transmission power, Interference level, Routing overhead and Node Mobility in AHCPN. The LETPOW algorithm noticeably enhances the performance of the system and improves average packet loss ratio Figure 4.7 and path lengths Figure 4.8.

Chapter 5

HYBRID LOAD POWER CONTROL ALGORITHM, HLPCA

5.1 Introduction

There are three directions identifiable in the case of power control [124]:

1. Selecting a power level that can maintain network connectivity, or which bounds the number of one-hop neighbours.
2. Completing the design of a power-efficient routing algorithm in the network layer.
3. Making changes to the MAC layer in an effort to support Sleep mode.

The size of a wireless network's growth positions it in such a way that decentralised mechanisms are most desirable when seeking to complete power allocation; this is highlighted owing to the fact that centrally controlled mechanisms involve added infrastructure and network vulnerability. In this vein, power control may be defined as the intelligent selection of transmit power in a communication system, centred on attaining sound within-system performance. As highlighted in [125], power management and power control methods as applied in wireless networks direct emphasis towards the conservation of energy and the trade-off of performances, with attention focused on ensuring metrics are optimised, as in the cases of a link rate, coverage range, network lifetime and network capacity. Should there be no central node to complete power control administration, it is more difficult to enhance network topology with energy-efficiency communication.

Accordingly, topology control algorithms that are asynchronous, scalable and localised are recognised as being especially attractive in the case of ad hoc networks. Furthermore, energy consumption overall, in line with adaptive outage probability specification, is optimised through the dynamic algorithm, which guarantees the worst outage probability too all users [126]. Upon the deployment of the nodes, their batteries are problematic to replace or recharge in a number of different application scenarios, with this almost impossible. As such, power consumption reductions are seen to be a valuable approach to ensuring network lifetime can be extended. In specific consideration to energy savings, all nodes' transmitting power can potentially be adjusted between zero and its maximum transmission power [127]. In the case of wireless ad hoc networks, power assignment is concerned with assigning all wireless nodes with power such that there is the presence of various necessary properties in the induced communication graph. In this regard, research carried out during more recent times have centred on establishing the minimum power assignment that can guarantee the connectivity or fault-tolerance of the network [128]. In this regard, there are three energy-efficient approaches with the capacity to achieve reductions in energy consumption at the protocol level: reducing the number of route request messages, thus achieving energy conservation, as the first approach, whilst the second and third approaches apply different means [129].

In an ad hoc network, power control cross-layering comprises a number of nodes with the capacity to wirelessly communicate without there being the presence of any fixed infrastructure, with MAC and network-layer information shared. In an ad hoc network, nodes utilise other nodes in the role of intermediate relays with the aim of sending packets to their destination. In the wireless network, the node plays the part of a router in information communication. Owing to the fact that nodes are more commonly operated through batteries, one critical consideration pertains to the preservation and efficiency of energy [130]. Transmission power assignment algorithm is recognised as offering one of the most valuable solutions in this regard when seeking to allocate initial power within the wireless environment. Moreover, as a result of the broadcast nature of such a wireless medium, ad hoc networks are further restricted by capacity and interference factors. In wireless technology, cross-layer design is recognised as able to enhance performance, with the optimisation of cross-layer defining a general concept of between-layer communication, taking into account specific smart interactions between them, and achieving improvements across the performance of the network. It seeks to couple network layer functionality alongside improving system-wide performance. The more conventional method in regards OSI layered models are able to acknowledge a subset of potential interactions in the cross-layer design. In consideration to quality of service (QoS) requirements, which are known to differ from one application to the next, the higher layers or network operations should be directed based on the information garnered at the MAC and lower physical layers. This particular work centres on MAC and network layer power control tools, meaning a number of different cross-layering designs may be applicable in the wireless network; however, in this case, the cross-layer from the physical through to the transport layer are considered.

Should power control be dealing in MAC, layer IEEE802.11 b stack build with the minimum and the maximum power values. In line with the transmission power represented by TX_{POWER}, PW_{max} is maximum power whilst PW_{min} is the minimum; in the Network layer, power control provides the most efficient power-aware routing optimal transmission power and further delivers the shortest path power routing. Accordingly, in the present case, the power assignment algorithm helps to deliver the most valuable power control solutions for both the MAC and the Network layer power control. Such a transmission power assignment algorithm is suggested in line with power control methods for single-hop and multi-hop wireless networks. The various obstacles in this suggested work include the section of a network in consideration to load. Notably, traffic and distance influence whether the load is high or low; when calculating distance between the receive and sender, Euclidean distance is applied. One further obstacle, which is technical in nature, is centred on establishing the most suitable level of power for all nodes through the use of *RSSI*. In this case, when Node A is transmitted by the sender to Node B, the receiver then measures the sender's signal strength with the use of RSSI. This further measures the received radio channel's power. The suggested model in this case is PW_{min} and PW_{max} transmission power assignment algorithm for single and multi-hop wireless ad hoc networks. In the case of the power assignment algorithm, power control methods are utilised in an effort to analyse the system[124].

In this chapter, Ad Hoc Cognitive Packet Networks (AHCPN), the algorithm of power control transmission, assignment results in a greater degree of efficiency in the network through the application of hybrid link power control algorithms, namely HLPCA which is Link Expiration Time Aware Distributed Power management algorithm, (LETPOW) and Load Power Control Algorithm (LOADPOW), deal with cross-layer power control applied for transmitting information across the various intermediate layers. Which is seen to place emphasis on the concept of transmission Power, in addition to *RSSI* (Received Signal Strength Indication), and Suitable distance between the receiver and the sender is calculated in the network by Euclidean distance. Furthermore, connectivity, Link expiration time, Power level. In this vein, the difference between the received power and transmission power for the amount of mobile nodes present within the hybrid power control algorithms, (HLPCA) network can be calculated with the use of the path loss model. In this regard, the key concept is concerned with enhancing the levels of delay, distance, throughput, packet loss, and energy savings in the network. This is achieved by communicating all packets with optimal transmit power in line with the HLPCA algorithm. Simulation has been performed through the adoption of the NS-3.26 simulator.

5.2 Energy Management in LOADPOWER Network

The figure 5.1 below provides an overview of energy management approaches, with the wide-ranging classifications of battery power management, transmission power management and system management. This work centres on the second of these through the adoption of the MAC and network layer cross-layer. Notably, MAC layer power control IEEE802.11 b may be defined as a set of 802.11 delivering wireless transmission in the case of wireless connectivity. The network layer is well positioned to provide power routing through an efficient approach centred on achieving transmission power optimisation[124].

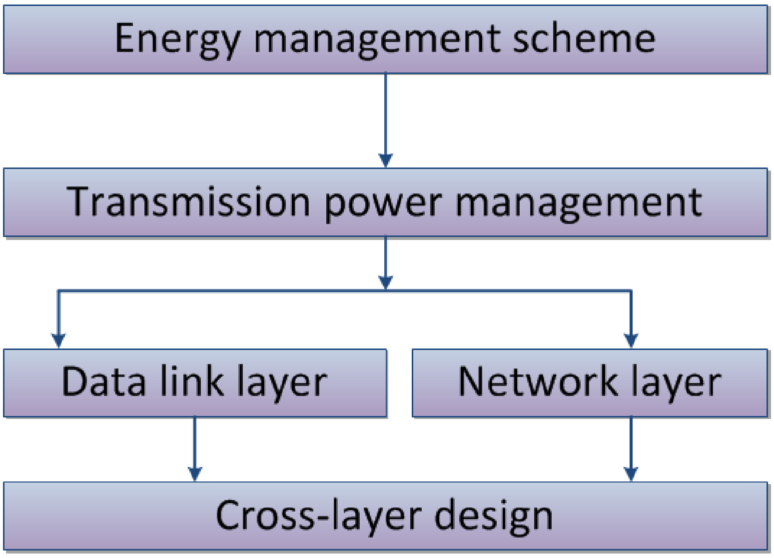


Fig. 5.1 LOADPOWER energy scheme [124]

5.3 Power Assignment and Transmission Scheduling

As has been highlighted by [124], there is the need for transmission scheduling algorithm to incorporate two different elements in mind of overcoming the two sub-problems associated with transmission scheduling and power assignment. There is the suggestion of two different types of downlink data transmission scheduling algorithms: in the case of the first, prior to transmission scheduling, power assignment is carried out; in the second case, transmission scheduling is carried out first, with power assignment carried out after. The performance of the two algorithms in the first instance, which utilise the same power allocation approach, undergo examination. It is identified that both of these algorithms demonstrate excellent levels in regards worst-case performance and asymptotically optimal average-case performance when there is the equal allocation of total transmission power across all channels. Overall, excellent average-case performance can be seen in both algorithms. It is further identified that the second type algorithms demonstrate improved performance when compared with the two algorithms of the first instance as a result of the equal time *power allocation method* [124].

1. **Power Assignment-EQ (Equal Power allocation):**

   The first type of downlink data transmission scheduling algorithms undergo development in line with the equal power allocation approach. Should the transmission power P be seen to be equally allocated to the C channels and the n transmission requests in equation 5.1:

$$P_i = P/C \tag{5.1}$$

For all $1 \leq i \leq n$, where is the average power per channel.

2. **Power Assignment ET (Equal Time Allocation):**

   The second type of data transmission scheduling algorithm centres on observation where, in an optimal schedule, all of the channels *{1,2,..., C}* carry out their transmissions of data at the same time. This can be easily proven by assuming that (s_i , d_i) is the last completed transmission request allocated power pi; (s_j , d_j) is the second last completed transmission request to be allocated power p_j. It can therefore be established that P_i can be increased and p_j decreased to ensure the simultaneous completion of the two transmissions, with the total transmission time decreased, as shown in equation 5.2. Accordingly, $p_1, p_2, ..., p_C$ and T can be determined as in:

$$T1_{p1} = T2_{p2} = ... = TC_{pC} = T \tag{5.2}$$

5.4 Power Allocation in Multi-user Relay Network

As noted in the work of [131], multi-user single relay wireless network is where the transmission of users' signals through to the destination is facilitated by the relay. If taking a wireless network N users, all of whom communicate with their destinations through the use of one relay, as detailed in the below Figure 5.2, the channel from User i to the relay is denoted as f_i, the channel from User i to Destination j (the direct link) is denoted as h_i, and the channel from the relay to Destination i is denoted as g_i. In this regard, this chapter considers two different channel models, namely the path-loss channel and the Rayleigh flat fading channel.

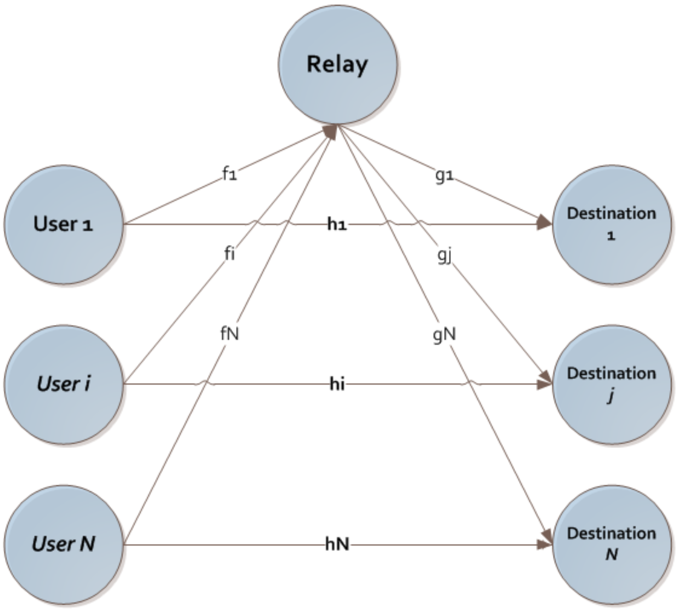


Fig. 5.2 Multi user relay network. [124]

5.5 PW_{min} and PW_{max} for LOADPOWER control transmission power assignment algorithm

As shown in Figure 5.3, the LOADPOWER domain is seen to be active in the network layer R(XI, X2, ..., Xn). All of the LOADPOWER network nodes determine the individual power level upon transmission. A cross-layer design is utilised in the power allocation of both MAC and the network layer. RSSI is carried out in order to calculate the signal strength received in the network's received nodes. All of the nodes, on an individual basis, assign their own power in line with the Pmin and Pm ax power control approach. The transmission power is determined for the data packets, whilst changes are made to the power level for all individual packets in the network. Notably, in the network layer, the power route module is seen to comprise DEST, NEXTHOP, METRIC and TXPOWER and ACK.

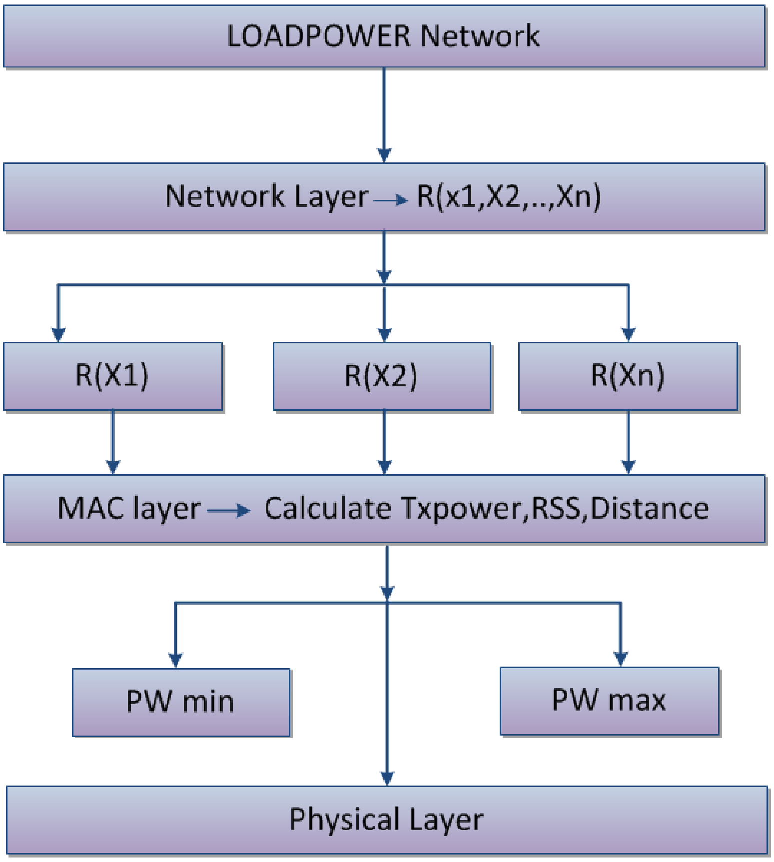


Fig. 5.3 Multi user relay network. [124]

5.5.1 Path Loss Model

In this study, the basic power loss model applied is recognised as a more simplistic version of that which is suggested in the path loss of a wireless link, which may be recognised in line with the variation between the transmit power PW_{tx} and receive power PW_{rx} detailed in equation 5.3,

$$PathLoss = PW_{tx} - PW_{rx} \tag{5.3}$$

As can be seen through the above equation 5.3 expression, a number of different effects are grouped together, with the inclusion of path loss under the term ‘Path Loss’, shadowing, and multipath fading. Importantly, the Path Loss term explains the collective result of such individual wireless loss mechanisms in decrease the degree of transmitted power to the signal strength received.

5.5.2 Algorithm - Assignment of transmission power

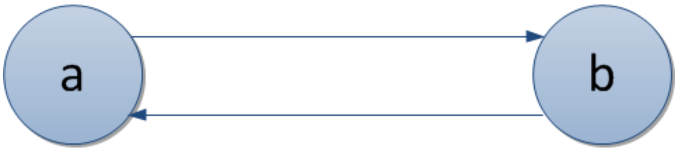


Fig. 5.4 Transmission from a to b. [124]

As detailed in the above Figure 5.4, transmission power assignment from A to B and B to A can be seen, with the sender transmitting a packet to B with a greater power PW_{max} whilst the receiver transmits a lower power level PW_{min}.

$$PW_{AB} \neq PW_{BA} \tag{5.4}$$

In equation 5.4, transmission control level of the Asymmetric link is used in assignment power.

Algorithm 3 Asymmetric link transmission power level is used in assignment power.[124]

```
Source:
Listen for the packet for the optimal transmission power level
Assign the transmit power for the receiver
Destination:
Receive the data packets from the source, calculate the RSSI of the packet from the source node
if sender is not ready in the list of nodes for which RSSI is unknown then
    Add the sender to the list then record RSSI
end if
if sender is on the list of the node for which the initial transmission power of the sender is unknown then
    use the initial transmission power of sender in step 12.
    Else
        Still need control packets from sender with record of the initial transmission power
end if
Calculate the new optimal transmission power level $T_{opt}$ .
Update the table with the newly calculated power $T_{opt}$
Send the new $T_{opt}$ to sender if RSSI has changed significantly of there is a time out.
```

5.5.3 Algorithm for PW_{min} and PW_{max} transmission power assignment Technique in single hop wireless network

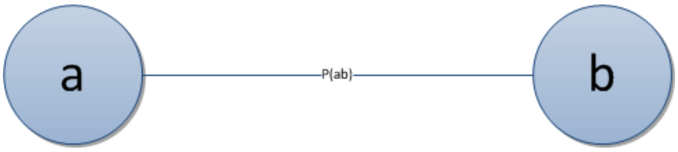


Fig. 5.5 Power control technique in single hop network. [124]

Algorithm 4 Power Control Algorithm in Single hop network [124]

```
Input: Single hop wireless network N
Output: Finding the power level for a to b
procedure Begin
    for each $P_{(ab)}$ do
        Calculate the $PW_{min}$ a and $PW_{max}$ a
        Calculate the $PW_{min}$ b and $PW_{max}$ b
        Calculate the $P_{(ab)}$ by Euclidean distance
        Transmit the min or max power from a to b /* a find the optimal power level to b
    end for
end procedure
```

5.5.4 Algorithm for PW_{min} and PW_{max} transmission power assignment Technique in multi hop wireless network

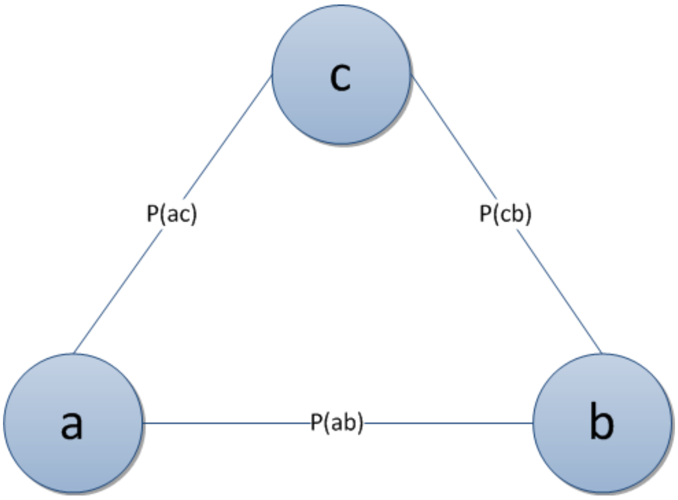


Fig. 5.6 Power control technique in multi hop network. [124]

Algorithm 5 Power Control Algorithm in multi-hop network [124]

```
Input: Multi hop wireless network N
Output: Finding the power level for a to b
procedure Begin
    for each $P_{(ab)}$ do
        Calculate the $PW_{min}$ a and $PW_{max}$ a
        Calculate the $PW_{min}$ b and $PW_{max}$ b
        Calculate the $P_{(ab)}$ by Euclidean distance
        if $P_{(ac)} + P_{(cb)} \leq P_{(ab)}$ then
            transmits with $P_{(ac)}$ for b
            Else
                transmits with $P_{(ab)}$ for b
        end if
    end for
end procedure
```

5.5.5 Euclidean distance

Euclidean distance may be recognised as the distance between two points, i.e. two nodes, where the sender transmission power PW_{rx} and receiver transmission power PW_{tx} may be determined through Euclidean distance. This is applied when seeking to measure the receiver to sender distance in the wireless network setting. In this regard, the distance between PW_{tx} and PW_{rx} for nodes a and b can be seen through the following [124]:

the distance between a to b and b to a is denoted by,

$$d_{(a,b)} = d_{b,a} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{5.5}$$

Distance calculation between any two nodes, say node a and node b is based on Euclidean distance given by equation 5.5.where x1 and x2 are the x-coordinates of nodes a and b respectively and y1 and y2 are the y-coordinates of nodes a and b respectively.

$$= \sqrt{\sum_{i=1}^{n} (a_i - b_i)^2} \tag{5.6}$$

5.6 Hybrid Load Power Control Algorithm, HLPCA

The below pseudo code algorithm 6 illustrates the hybrid “LOADPOWR and LETPOW algorithms as shown in section 4.2; the pseudo code has been started with initializing parameters. For each node, we perform step 4 to step 9. Step 4, step 5 and step 6 determine the connectivity degree, link expiration time, node mobility factor from LETPOW Algorithm. Then in step 7 and step 8 estimates the minimum power, maximum power and distance between nodes using the LOADPOW Protocol. These two algorithms are combined by defining a condition in step 9, based on which the nodes perform data transmission. If the condition is not satisfied, then that particular node sleeps until its expiration time is reached.

Algorithm 6 Hybrid Load Power Control Algorithm, HLPCA

```
procedure Begin
    Set $P_{T_i} = P_{T_{initial}}, compute\ \psi_i$ , $set\, timer = \tau_{id}$ , Soft state_Timer $T_i$, Link expiration time=$l_i$, Power level $(E_{ij})$, energy = $\varepsilon$ , node identity $n_{id}$, Distance between two node $i$ and node $j$ = $(D_{ij})$.
    for each $n_{id}$ do
        Compute connectivity degree ,$\psi_{DEG_i} = \frac{\psi_i - \psi_{i_{max}}}{\psi_{i_{max}} - \psi_{i_{min}}} + \frac{l_i - l_{i_{min}}}{l_{i_{max}} - l_{i_{min}}} + n_{id}$
        Compute link expiration time factor $l_{FAC_i} = \frac{\varepsilon_i}{\varepsilon_r + N_o}$
        Compute node mobility factor $m_{FAC_i} = (n_i - n_j) \times (1/\varepsilon)\, where\ \varepsilon > 0$
        Compute $PW_{min}$ and $PW_{max}$
        Compute $D_{ij}$ and RSSI
        if $\psi_{DEG_i} < \psi_{DEG_{Th}}$ , $l_{FACi} < l_{FAC_{Th}}$ , $m_{FAC_i} < m_{FAC_{Th}}$ , $(D_{ij}) < (D_{Th})$ then
            Perform multi hop transmission
            Else
                Sleep until timer expires
        end if
    end for
end procedure
```

5.7 Simulation and Result

An (AHCPN) was implemented and combined with HLPCA Algorithm by using NS-3.26. The experiments involved carrying out establishment observations and route use in the network. All experiments focused on the network operation for 1000s, as shown in Table 5.1 .

Table 5.1 **AHCPN Simulaltion Parameters**

Simulator	**NS-3 version 3.26**
Simulation time	1000 s
Traffic	Constant Bit Rate UDP
Link data rate	IEEE 802.11
Propagation Model	Two Rate Ground
Maximum Transmission Power	0.660 W
Reception Power	0.395 W
Idle Power	0.035 W
Initial Energy	10000 J

Totally, there are 45 nodes in this simulation, and run the simulations on the transmission with and without power control algorithms. In transmission with power control, four methods has been applied: Lent et al.,topology[9], DISPOW, LETPOW and HybridLoadPower algorithms. The last algorithm is the proposed approach as highlighted in Figure 5.7. All nodes are recognised as starting with a full battery energy.

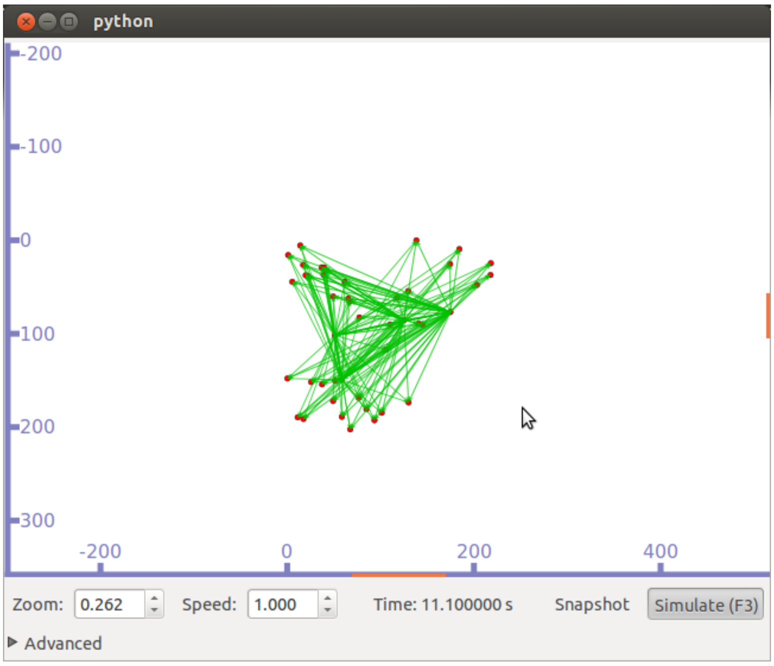


Fig. 5.7 HLPCA Simulation topology.

Figure 5.8 shows the relation between the delay of data transmission and the load of data for five methods. It can be observed that there is sensible transmission delay of TX without control starting at around 4×10^4 bps , whilst in the case of the TX with control (PLR), TX with control (DISPOW) , TX with control (LETPOW) and TX with control (HybridLoadPower), the sensible transmission delay started around 6×10^4 bps. Also , it can be seen in Figure 5.8 that the highest and lowest data transmission delay trends were observed in TX with control (PLR) , TX with control (LETPOW) and TX with control (HybridLoadPower), respectively. It can be observed in the figure 5.8 that, for a given value of load, the delay in TX with control (LETPOW) was found to be highest values of delay compares with TX with control (HybridLoadPower).

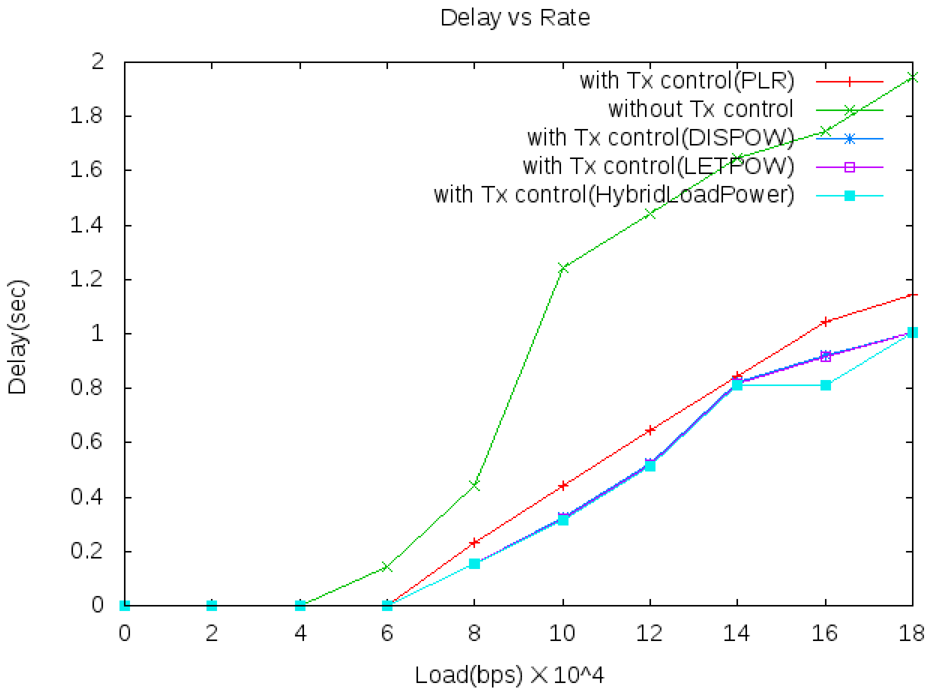


Fig. 5.8 HLPCA method Delay vs. Rate.

Figure 5.9 presents the comparison between the numbers of throughput for a varied number of loads. All of the methods experience the same trends. From Figure 5.9, it can be observed that there has been a slight increase in the number of throughputs for methods TX with control (PLR), TX without control, TX with control (DISPOW) , TX with control (LETPOW) and TX with control (HybridLoadPower). Specifically TX with control (DISPOW), TX with control (LETPOW) and TX with control (HybridLoadPower) have the same pattern for case of throughput, but the throughput is 14×10^4 slightly enhance for (LETPOW) algorithm from others and the throughput is enhance at 4×10^4 for (HybridLoadPower) algorithms.Figure 5.9 shows the throughput of all the system.therefore load and the throughput are not equitable.

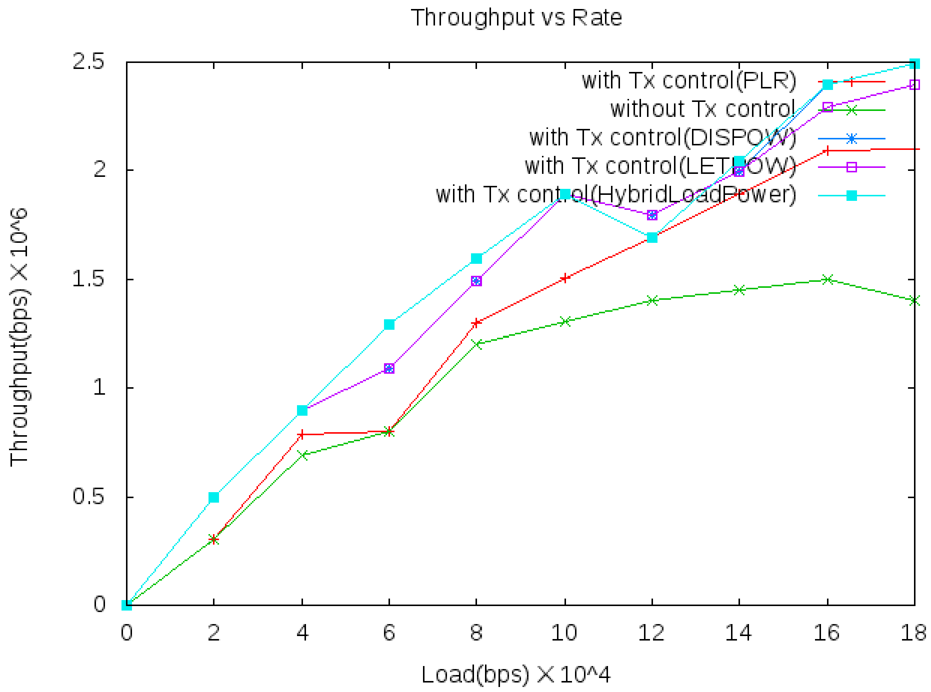


Fig. 5.9 HLPCA method Throughput vs. Rate.

Figure 5.10 describes the Relationships between the packet loss ratio against load of data for five methods. As can be seen in the graph, there is sensible packet loss from nearby zero to around 6×10^4 bps for normal transmission (TX without control). The packet loss ratio starts increasing significantly when the transmission load is larger than 6×10^4. On the other hand, the PLR, DISPOW, LETPOW and TX with control (HybridLoadPower) algorithms experienced nearby zero packet losses at zero data load. Subsequently, packet losses rose gradually until reaching around 0.4 for TX with control (DISPOW), 0.425 for TX with control (PLR), 0.325 for TX with control (LETPOW) and 0.2 for TX with control (HybridLoadPower).

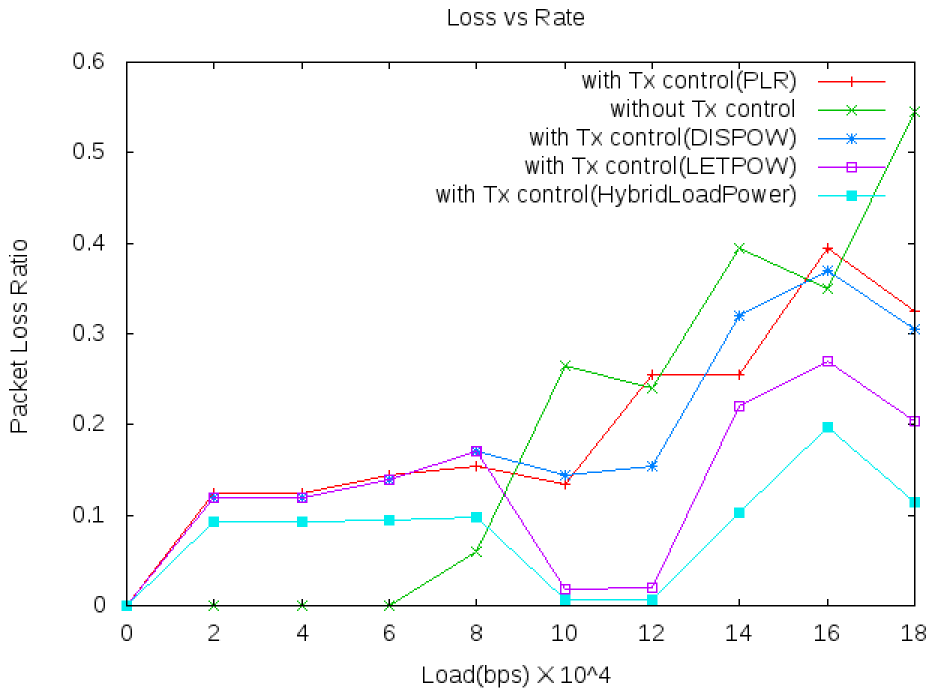


Fig. 5.10 HLPCA method Packet loss vs. Rate.

Figure 5.11 shows the Relationships between the path lengths against the load of data for the five methods. It can be seen that both transmission with TX with control algorithm PLR, DISPOW, LETPOW and HybridLoadPower. Have almost the same trends until load value around 4×10^4 and the trends different beyond this vale, but the HybridLoadPower algorithm has better performance and stability.In Figure 5.11 shows the maximum path lengths is two.

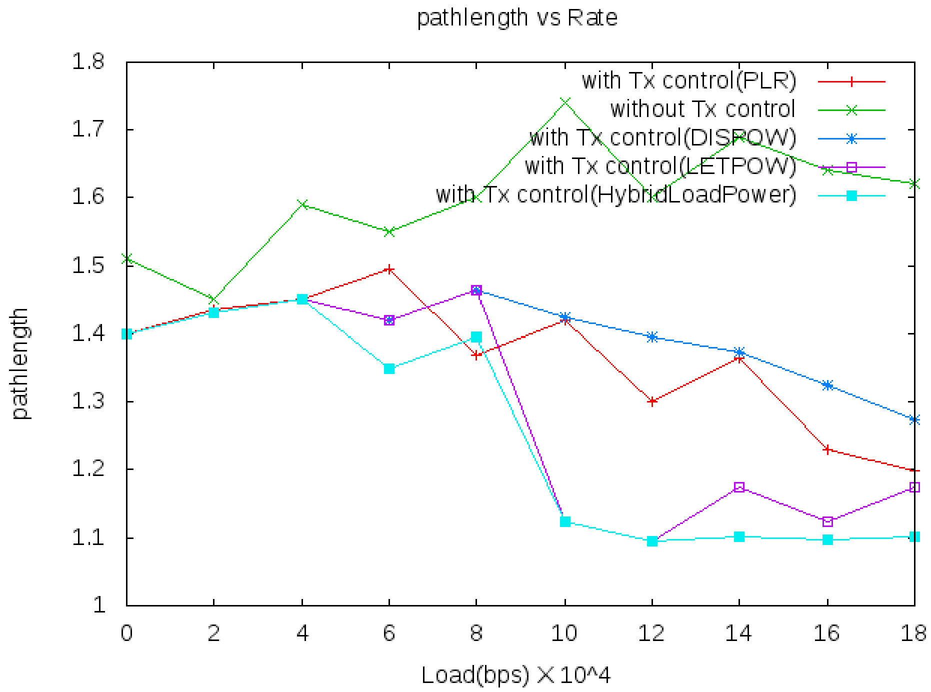


Fig. 5.11 HLPCA method path length vs. Rate.

Figure 5.12 illustrates the amount of energy consumed per data byte as the load of the network increases. When the number of loads is near to zero, all of the algorithms have two energies consumed. In the transmission without control, this energy dropped sharply until around 1.1 J, when the load is seen to be 40 Mbps. Then, it remained stable at 1.1 J until the end of the simulation. In the transmission with control, the energy consumed went down to 0.9 J for PLR and 0.8 J for DISPOW, LETPOW and HybridLoadPower at 20 Mbps. Later, both the energy decreased slowly at approximately 0.6J for PLR and 0.3 J for DISPOW, LETPOW and HybridLoadPower algorithms. Specifically TX with control (DISPOW), TX with control (LETPOW) and TX with control (HybridLoadPower) have the same pattern for case of energy consumption, but the HybridLoadPower algorithm has better performance. In short, transmission with control (LETPOW) has the highest energy consumed compared to transmission with control (HybridLoadPower).

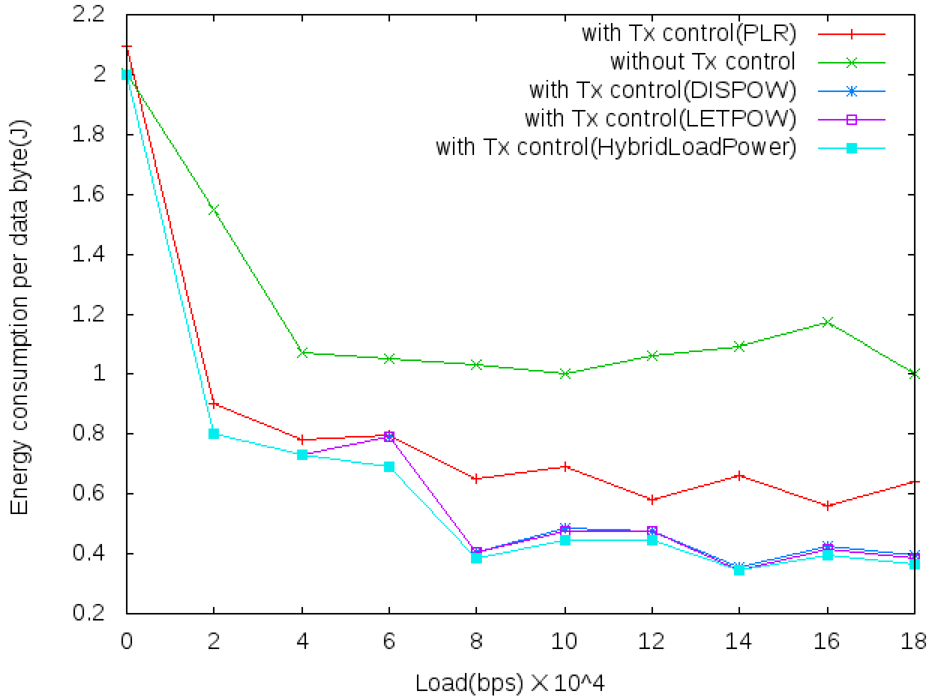


Fig. 5.12 HLPCA method Energy vs. Rate.

5.8 Summary

We have presented AHCPNs with DISPOW, LETPOW and HybridLoadPower power control scheme and compare with Lent et al., [9] method, which seeks to decrease power utilisation at the nodes. Nodes were enhanced through decreasing their transmission power, meaning the nodes energy availability does not notably decline. The result shows DISPOW, LETPOW and HybridLoadPower algorithms have almost better performance, specifically, in this chapter, we deliver new power control algorithm (HybridLoadPower) which focus on both Link Expiration Time and depends on the notion of energy, Received Signal Strength Indication (RSSI) and the distance in AHCPNs. The HybridLoadPower algorithm noticeably enhances the performance of the system and improves throughputs, average packet loss ratio, path length (hop) and energy.

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

This protocol has provided an assessment and generalised overview of the AHCPN protocol, with a power control algorithm, which takes prior research on AHCPN with the aim of providing an enhanced functionality of mobile ad hoc networks.

In the case of AHCPNs, smart packets (SPs) make full and complete use of power broadcasts to establish a complete or even partial flooding, which enables nodes to garner neighbouring data, whereas SPs move on the network owing to the recognition that flooding is costly with regard to the utilisation of resources. Wherever possible, SPs implement unicast-based transmissions in line with the CPN routing algorithm. The problem identified as needing to be overcome in this work centres on the dynamic selection of the transmission power of nodes in such a way that aligns with changing conditions commonly identifiable in mobile ad hoc networks, with the aim of ensuring the most optimal performance. This is achieved through ensuring low delay, low levels of energy consumption, and network capacity of a high degree. The solving of the thesis problem is not simple in consideration to the following factors:

Power adjustments that are not synchronised could mean unidirectional links are created, which in turn cause the failure of some routing algorithms. A wealth of the present solutions introduced, including DDISPOW, LETPOW and HLPCA algorithms that is notably centred on power control in ad hoc networks, only recognises connectivity in the network. To the researcher's knowledge, thus far, no solutions to power control have been presented that take into consideration QoS of a flow. In an ad hoc network, transmission power control is known to have a multi-faced effect on the network's QoS. In this work, the way in which transmission power control influences network performance has been demonstrated, such as in regards to blocking, loss and delay. Moreover, efforts have also been directed towards highlighting the effects of the control of transmission power and the reliance of such on the state of the system, with network performance seen to degrade when there are low traffic conditions, whilst heavier traffic conditions are able to improve the user's QoS experience. Accordingly, there is a need to adopt power control in such a way that network performance will not be compromised. In this vein, it is essential that the control strategy considers performance factors.

6.2 Future Work

Although CPN has shown attractive performance compared with the traditional packet switching network,there are still some aspects that can be further improvement and evaluated:
Distributed MAC protocol for Successive Interference Cancellation (SIC). However, AHCPN lacks for connectivity management and resources. To deal with these issues, SDN (Software Defined Networking) is invoked. SDN controller act as a Global Controller where we get the following benefits:

1. Network Management
2. Topology Management
3. QoS Management
4. Energy Management
5. Security Management

In SDN controller, Power Manager is introduced for managing the transmission of power nodes using Fuzzy Rules with Multi-objective PSO based Pareto Solutions.

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