Feasibility of using SWAN as an underlying model for QoS provisioning in Overlapping Wireless Mesh Networks

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DEDICATION

I dedicate this work to my beloved parents, my dear husband Farhan and my lovely and sweet daughters Sarah and Zainab

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DECLARATION

I hereby declare that this Thesis **"Feasibility of using SWAN as an underlying model for QoS provisioning in Overlapping Wireless Mesh Networks"** neither as a whole nor as a part has been copied out from any source. It is further declared that we have done this research with the accompanied report entirely on the basis of our personal efforts, under the proficient guidance of my supervisor Dr: Muhammad Sher. If any part of the system is proved to be copied out from any source or found to be reproduction of any project from any of the training institute or educational institutions, I shall stand by the consequences.

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PROJECT IN BRIEF

Project Title:	**Feasibility of using SWAN as an underlying model for QoS Provisioning in Overlapping Wireless Mesh Networks**
Undertaken By:	**Gul-e-Rana** **Registration# 519-FBAS/MSCS/F08**
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ABSTRACT

Wireless mesh network (WMN) is an emerging field in the world of wireless networks which provides scalability and proficient solution to the users having less or no mobility for the sake of internet and/or intranet access. Since, the deployment of such mesh networks may be with or without planning, therefore service areas may be overlapped to some extent or completely, being unaware of each other's existence. Even though, the nodes may share same geographical area, in the absence of any mechanism to communicate with one another, frequent collisions may be encountered on both sides. Absence of coordination among these networks results in the performance degradation of individual networks. Communication among such networks is only possible through those nodes which occur in common area called bridge nodes as they act as a bridge between networks. Only few nodes may be designated as bridge nodes to incorporate inter-network communication. Hence, there will be extra load on these bridge nodes as compared to other nodes as they have to switch channels to become compatible wit both domains. Thus, efficient multi channel accessing and channel hopping technique is required. However, in case of congestion, bridge nodes may become bottle neck and result in dropping of flows or reinitiating of flows which will decrease performance and throughput. So QoS scheme is needed to handle above mentioned problem. This thesis focuses on an attempt to properly coordinated and inter-worked these overlapping wireless mesh networks and check feasibility of SWAN for QoS provisioning in terms of handling congestion and minimizing packet drop. Simulation are carried out in different scenarios with different traffic types and loads and compare results with normal scenario. The percentage of packet drop with SWAN is less than normal scenario. Our work suggest that Adhoc protocols and QoS solution can work as well on overlapping WMNs and increase their performance by keeping their original behavior does not change.

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WMNs	Wireless Mesh Networks
QoS	Quality of Service
VoIP	Voice over IP
MAC	Media Access Protocol
UDP	User Datagram Protocol
TCP	Transmission Control Protocol
RTS/CTS	Request to Send/Clear to Send
DCF	Distributed Coordination Function
MANET	Mobile Adhoc NETwork
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
OMNeT++	Objective Modular Network Testbed in C++
BN	Bridge Nodes
AP	Access Points
NAT	Network Allocation Table
VPN	Virtual private network
WLAN	Wireless Local Area Networks
SWAN	Stateless Wireless Adhoc Network
FQMM	Flexible Quality of Service Model
HQMM	Hybrid Quality of service Model
ECN	Explicit Congestion Notification
AIMD	Additive Increase Multiplicative Decrease
ESWAN	Extended Stateless Wireless Adhoc Network
PHC	Partitioning Hierarchical Cluster
POC	Partially Overlapping Channels
SSCH	Slotted Seeded Channel Hoping
RSVP	Resource ReserVation Protocol
NAV	Network Allocation Vector
UML	Unified Modelling Language
FTP	File Transfer Protocol

Chapter No 1

INTRODUCTION

In wireless communication, data [22] is shared and transferred between users without the need of cables and wired links; hence infrastructure cost is saved. In the absence of wires in wireless networks, air is used for transmission of data in the form of electromagnetic signals during communication. The accurate and increased communication of data in wireless area networks requires provisioning of Quality of Service (QoS) and sophisticated designs. Wireless networks are considered better option than wired networks in daily life usage [26] due to their unique features, as these networks do not require extensive cabling and are faster, reliable, easy to use and less costly. The mode of operation of wired and wireless is different but user expectations from both networks are same. In beginning of networks history there were fewer types of applications and traffic which consisted mostly of data traffic that did not require any differential treatment.

With the time [42] multimedia applications arise and get important position among different wireless networks. Multimedia applications are different from best effort and required different level of services. Provisioning of QoS to such applications is very difficult and expensive [12] in wireless mesh network due to limited bandwidth and network capacity, insufficiency of simple priority and different service requirements of real-time multimedia applications which have different service requirement. But users want to get same service level and performance as they receive for best effort.

1.1 Wireless Mesh Networks

Wireless mesh network (WMN) [42] is an emerging field in the world of wireless networks which facilitates great many users in different areas by providing broad band internet access without the need for heavy and costly cabling. Radio nodes organized themselves in the form of mesh structure to develop a wireless mesh network. WMN have many benefits [26] over other networks like low up-front cost, easy network formation and maintenance. Also these networks can quickly recovered them from any node or link failure and have adjustment ability with any WMN nodes communicate with one another through multihop routing and there exists many alternate options for data to reach their intended destination in case of break down of any link, by one way or the other. As field of WMN is growing day by day, it become clear that they can fulfil the varying requirements of future generation of real time applications such as VoIP, video and audio on demand etc. For this purpose they have to provide advance end-to-end QoS guarantees to real time applications [10]. In WMN nodes can be mobile where routers have normally no mobility and no constraint in terms of resources. Additionally, WMNs have stable mesh backbone, so QoS provisioning can be comparatively easy task than MANET [42].

1.1.1 Architecture of WMN

There are three types of WMNS architecture [33, 34, 42]:

- **Infrastructure/backbone WMN**
- **Client WMN**
- **Hybrid WMN**

1.1.1.1 Infrastructure WMN

In such networks a backbone is developed by routers to which different clients and networks are attached. Different technologies including IEEE 802.11 technologies are used for developing these networks. This infrastructure/backbone [42] WMN have self healed, self configured and stable links managed by mesh routers. Edge routers have gateway functionalities through which they connect to internet and other networks. This infrastructure provide backbone for conventional clients and different wireless networks are connected to WMN through this backbone and WMN integrate and communicate with these networks by means of its connecting abilities embedded in gateways. Typical clients are attached with backbone routers by means of their particular interfaces.

1.1.1.2 Client WMN

In client WMN clients have the major role and they can route their data directly with out the need of routers. Peer-to-peer connections among clients are used [33,42]. There is no need of gateways or routers in this type of WMN. Clients are the basic part and form network. Clients perform different activities like routing, self-configuration of network and end-to-end applications of customers. Devices in client WMN have only one type of radio but have more end-to-end needs in contrast to infrastructure WMN and communication is between node to node.

1.1.1.3 Hybrid WMN

Hybrid WMN is a combination of Infrastructure and client WMN shown in figure 1.1. Mesh clients have direct connections with other mesh clients and can access networks and communicate with other clients directly as well as via mesh routers [34]. It is the most improved and developed type and have capabilities of both above mentioned types. It has the ability of connectivity with many different types of networks including the Internet, cellular networks and sensor networks as well as having larger coverage and more connectivity among clients inside mesh [42]. It is more flexible and better option than both client and infrastructure WMN.

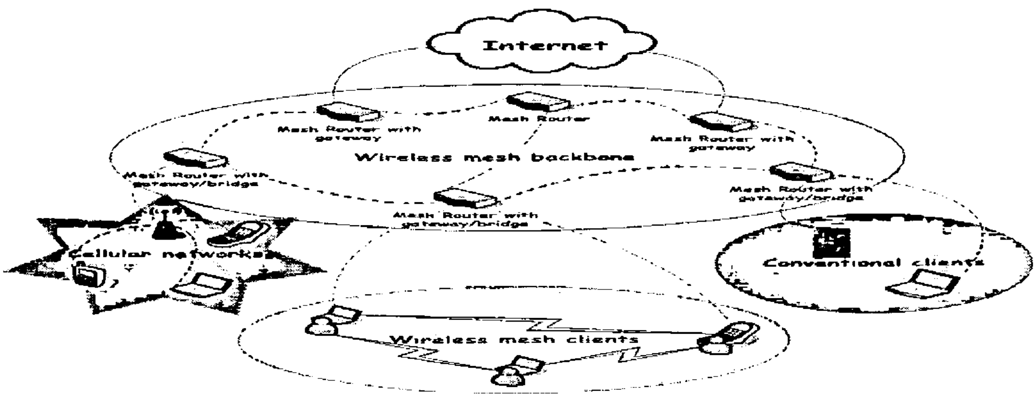

Figure 1.1: Hybrid Wireless Mesh Network [42]

1.1.2 Types of clients in WMN

There are two types of nodes in WMN i.e. routers with gateways functionality and clients [33]. Routers are responsible for handling transmission of data among different sources and destinations as well as have gateway /bridge functionality through which WMN link up and coordinate with many different types of networks.

Mesh clients also have the abilities required for communication in WMN. They can forward data on the behalf of other nodes but can't be used as connecting bodies like routers for making connections and communications with other networks. Mesh clients have one radio so their hardware and software requirements are less than routers. Mesh routers are only of few types where a client ranges from laptop, desktop computers to IP phone and so many others. Generally mesh clients are mobile and routers are static and have no power constraint [42]. Mesh clients are also termed as nodes.

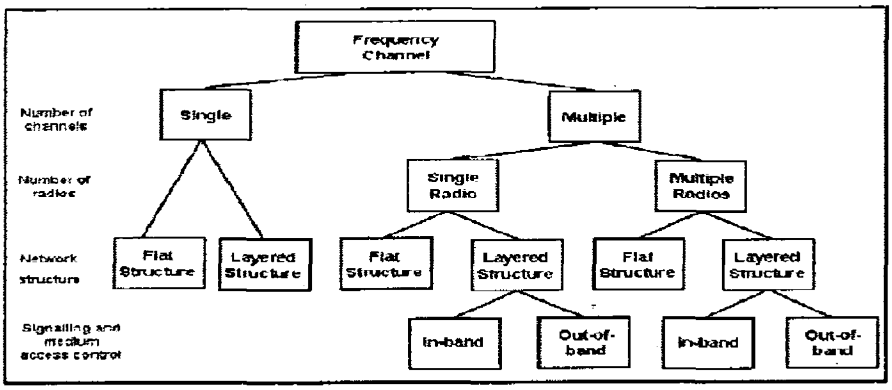

Figure 1.2: Classification of Wireless Mesh Network [9]

1.1.3 Characteristics of WMN

Following are the different characteristics of WMN [33, 42].

- **Multi hop wireless network**

  WMN is a multihop network which enhance the coverage area by providing increased and transparent connectivity among users in different areas with higher throughput, less interference between the nodes. Provide more options for users to send their data to a particular destination through multiple paths.

- **Self-forming, self-healing, and self-organizing networks**

  WMN are highly responsive and automatically healed, organized and maintain themselves in response to failure or addition of any node or any change in the networks topology [34].

- **Mobility Constraints**

  In WMN intermediate routers and gateways are normally static where clients can be static or can have movement.

- Due to flexible architecture WMN have low up front cost, can be easily deployed and compatible with any failure, and hence increase performance of network.
- **Power Constraints**

  Mesh routers and gateways have more resources than mesh clients. Mesh clients have limited battery power as compared to routers which have no constraint for power consumption.
- **Compatibility**

  IEEE standards are normally used to develop wireless mesh networks. Due to this reason it should work easily with other Wi-Fi networks and different 802.11 based networks.
- **Support to Multiple types of network access:**

  WMN provide backbone through which different networks are connected to them and WMN using its gateways, coordinate and communicate with other networks attached to it through backbone. Through WMN we can access the backhaul internet [35].

- **Ad-hoc networks are usually taken into consideration as a subset of WMN**

  A WMN can be considered as a multi-hop Mobile Ad-hoc Network (MANET) with more coverage area and extra qualities [14].

1.1.4 Applications of WMN

Wireless mesh networks [9, 42] have many advantages and wide range of applications. These applications can't be as efficiently provided by other wireless networks like adhoc networks as WMN support them. Different applications of WMN are briefly describe in the following:

- Used in homes for providing broad band internet access to users.
- For manufacturing electrical equipments with low cost as compared to using old methods.
- Metropolitan area networks.
- In transportation systems for recording positions of drivers, vehicles etc.
- Used in hospitals for handling health and medical records of patients.
- Used in banks and other areas as security and rescue system in case of emergency.

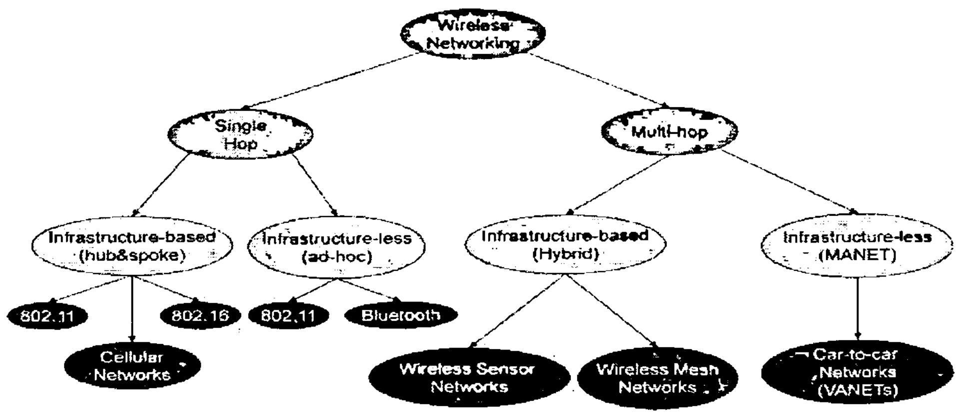

Figure 1.3: Taxonomy of Wireless Networking [38]

1.2 Quality of Service (QoS)

Quality of Service (QoS) is very important topic in networking and become very challenging in case of wireless and mobile networks. Reliable network performance was important in networks for many applications but with the development of multimedia applications requiring varying set of resources and increased amount of real time transmissions on internet, QoS guarantees getting more importance in wireless networking [37]. The achievement of a certain performance level and provisioning of differential treatment to different applications by network is called QoS. The differential treatment is in terms of different QoS parameters like fixed bit rate, bandwidth delay, throughput, packet loss etc, which differ from application to application. QoS guarantees are important and challenging task in wireless networks. As wireless networks have limitations in terms of bandwidth, capacity and unpredictable node movement which can't be controlled. WMN is also a wireless network and has the same problems [12]. QoS is very challenging and necessary in WMN. The reception and arrival of data for multimedia application should be very fast otherwise their quality will be suffered due to continuous interruptions [42]. QoS is the measure of level of service availability and transmission quality of network by means of different QoS parameters to fulfill different resource requirements of flows [36].

1.2.1 Objectives of QoS

QoS is very important in nowadays networks [36]. By QoS the priorities of different flows are set and some flows are given preference over others due to their importance. By this way flows got required and reliable services to attain their desired performance level. Violation of any networks rules and increased traffic load on network cause congestion which have direct impact on many QoS parameters like packet loss, throughput, delay etc. For avoiding congestion normally priority queues are used to keep the important traffic unaffected and to accommodate extra load or changes in network without effecting overall network performance.

Following are the different objective of QoS [36]:

- Efficiently utilization of dedicated bandwidth.
- Minimizing loss rate and improving throughput.
- Avoiding and managing network congestion.
- Mission critical applications should be preferred over other network applications.
- Voice and video which are sensitive to delay should be carefully handled and treated.
- Quick response to violation of rules in network and changes in network traffic flows.

1.2.2 Why QoS

QoS is the need of the day due to the following reasons:

- Real time applications have increased resource demands as compared to other applications. So to fulfill the Changing traffic demands and service requirements of Voice, Video, and Data applications.
- Different applications require different bandwidth to reach certain level. To avoid violation in usage of available bandwidth for multiple applications, QoS is required.
- To avoid congestion in network and guarantee of SLAs (Service Level Agreement) for priority traffic in networks.
- Efficient and optimal utilization of bandwidth utilization[36]
- Value added applications like Real time audio video, mission critical applications have different service requirement which can't be provided by typical best effort networks [9].

1.2.3 QoS Parameters

Parameters are the measurement metrics for checking that how much services offered by network are used for the achievement of a particular level of performance. Following are the different parameters used for measurement of performance level of different applications by using offered resources:

- Network availability

- Bandwidth
- Delay
- Packet Loss

All these parameters have direct impact on network performance and are affected by changing network behaviour [42].

1.2.3.1 Network Availability

Network presence and availability to users and nodes is very necessary and has direct impact on QoS. Both users and applications cant afford the unavailability of network even for a short while because all activities and communication process will be effected and result is degraded performance..

1.2.3.2 Bandwidth

Bandwidth is also very important parameter. Bandwidth requirement vary from application to application. Real time applications which are normally in burst, required more bandwidth than best effort.

1.2.3.3 Delay

Delay is the total time that an application spends in the network from its first time entry in network to the time leaving the network. Audio and video applications can't afford delay; otherwise result will be of poor quality and with interruptions.

1.2.3.4 Packet Loss

Any problem on physical medium during communication results in packet loss. In wireless networks packet loss or drop is due to three reasons mainly that include congestion on nodes, malicious node or error on channel [28]. Whenever nodes detect congestion, they drop packets which are re-transmitted later.

When there is more congestion, result is more packet drop and more re transmissions, which consume more bandwidth. Result is bandwidth wastage and degraded Quality of service. It means congestion should be handled efficiently to avoid packet drop and re-transmissions to save bandwidth and improve throughput. We can say that congestion has direct impact on network throughput and performance.

1.3 Overlapping Networks

We normally consider our network as our private property and only belong to us, our group, family or organization and wanted to draw its boundaries. So that no one other than us can use it. But this doesn't usually happen in reality. We can't define point from where our network start and where end. No matter we are a person, group, organization or country, we all are connected and intersected with one another and our networks overlap with the neighboring network. We can define the phenomenon of overlapping networks as the networks whose service area got overlap and have many AP's/routers/nodes belonging to both networks. When two or more networks exist in the neighbor of one another and have no boundaries, they got overlap and result is an area where AP's of both networks occur [3].

An overlapping network is formed when we want to make a connection using VPN (Virtual Private Network) client to another network using identical IP addresses which result in overlap i.e. our system in university is assigned IP address i.e. 192.168.12.10 by campus router privately, another system in nearby office is using the same address. When the client wants to connects to internet or with other network, it has its home network IP address which is its source IP address. The gateway considers this as an internal address of the network. By this way networks become overlap and our VPN connection is refused to establish [3].

1.3.1 Problems with/due to Overlapping Networks/Channels

a) Due to overlapping networks we face problems in logging into our network by using VPN although connection setup has no problem and is successful but we cant log in. This occcur when networks of two different organizations overlap and router of one network assign address to our system which match with 2nd network any machine

b) IP-NAT Overlapping: NAT is used to connect networks to internet through private, non-routable addresses where there is normally no overlapping between address spaces of inside and outside network. But in some cases there is overlappig between addresses which cause problems. Overlapping occur when two organizations combine and may use same addressing scheme, a network connect to internet using only a valid internet address not a designated private address, false assignment of a address of a particular company which is using it for so many years to another company and result is two companies using same addresses. In all these situations overlapping occurs and cause serious problems because due to this NAT cant differenciate between public and private addresses and cant tell whether destination is within the network or outside [46]

c) The main problem due to transmission on overlapping channels is interfernce which is an unavoidable problem in wireless networks. Communication on their neighboring nodes or channels is also effected by this interference and is called adjacent channel interference.[44]

d) If two networks become overlap in a service area and there is no form of communication between these networks, there will be a significant decrease in their performance and throughput[20, 23].

e) If two networks overlap and single common channel is used for communication among multiple cells of networks. Then flow of traffic to one destination will effect other neighboring destinations and creat collision on channel and will disrupt flows to other destinations.[2]

1.3.2 Utilization of Partially Overlapping Channels

It is not necessary that overlapping channels always creat problems and cause interference and decrease performance of networks. Certain mechanisms can be applied to take advantage of these partially overlapping channels and made them useful. Following are the some advantages/utilization of partially overlapping channels.

- The use of only non- overlapping channels for communication waste bandwidth. Use of Partially overlapping channels with completely orthogonal channels improves network throughput and can be use for continous transmission between nodes by keeping the distance less then interference range of nodes [40].
- Partially overlapping channel improves throughput capacity of mesh networks as well as increase the connectivity of multihop networks by extra gateways or routers [45].
- Communication among non-overlapping channels nodes can be accompalished by Partially overlapping channels by forwarding flows among them.

- Partially overlapping channels can be use to improve performance and re-usability of WLAN and made communication of nodes having single radio interface more effecient with their neighbors.
- Partially overlapping channels reduce the strength of signal during transmitting data form one channel and receiving on other channels which improves the re-usability of only one channel without interference and improves the capacity of network [51].

1.4 Research Motivation

With the passage of time, the use of WMN is increasing day by day and has a great variety in providing services to users in different areas including homes, hospitals, banks, industry, offices, commercial areas to economical areas and many more. The so many applications of WMN is only due to its unique features which make it different from other wireless networks. WMN have many advantages over other wireless networks. WMN has become the first choice of researchers nowadays, because it has low setup cost and can be easily maintained. Additionally, data transmission is reliable and it can integrate with other networks. The performance of different traffic flows are affected and degraded if they are not getting resources and services necessary for them, up to this level which they required. It means QoS is a key issue to be tackled in wireless mesh networks where majority of traffic is broadband in nature and their Quality of Service requirements vary from application to application. In WMN the flow of traffic is normally to or from gateway.

QoS is considered important in individual as well as multiple WMNs when they become overlap in a service area. When different people deploy WMN according to their own way, they become overlap either completely or partially and results with multiple AP's of different networks in one area. This way, intra-network communication between nodes can interfere with the transmission of neighbouring network. Hence, reduction in throughput and capacity of individual networks may be experienced. There are multiple networks having different channels and may be homogeneous or heterogeneous. This thing imposes various design challenges. Two overlapping domains can only interact through those nodes which occur in the overlapping area termed as bridge nodes. Since few bridge nodes will handle a lot of traffic so problem of congestion arises and also there will be degradation in performance of different traffic flows.

1.5 Problem Domain

When different WMN are deployed by different organizations they may overlap on each other being unaware of each other's existence. Having no form of communication with one another, although these networks will have their nodes in common area, frequent collisions may be encountered on both sides. If such networks have AP's in one service area but have no coordination they will face serious problems and throughput and their performance will be significantly decreased. Communication among such networks is only possible through those nodes which occur in common area called bridge nodes as they act as a bridge between networks.

Since, all nodes in common area cannot be selected as bridge nodes, because if all nodes are selected this will be useless. Only few nodes act as bridge nodes which are share between both domains and can handle traffic of both domains. Each domain has its own channel and traffic. So there will be extra load on these bridge nodes as compared to other nodes and also they have to switch channels to become compatible wit both domains. Hence, efficient multi channel accessing and channel hopping technique is required. There will be congestion on bridge nodes which results in dropping of flows or reinitiating of flows which will decrease performance and throughput. So QoS scheme is needed to handle above mentioned problem.

1.6 Proposed Approach

In our proposed solution we develop two wireless mesh networks which are partially overlapped in their service area and having nodes in this area termed as bridge nodes. Both networks are equally distributed. These networks require coordination among them which is provided by bridge nodes which act as a connecting link between two domains. The destination of one network exists in the other network. Traffic of one network pass through bridge nodes and reach destination. Bridge nodes can be shared between networks or dedicated to their network. As there are few bridge nodes so there will be congestion on these bridge nodes and packet will be dropped due to congestion which results in increase in delay and decrease of throughput.

So to show effect of congestion on overall system and packet drop, we implement SWAN QoS model initially and later tailor it according to feasibility of overlap networks for minimizing congestion and packet loss.

In our proposed solution firstly two overlapping domains are properly coordinated and inter-worked, then check behavior of bridge nodes, effect of channel hopping on packet delivery ratio and feasibility of SWAN for QoS provisioning in terms of handling congestion and minimizing packet drop. The possibility of SWAN whether it works for two independent networks is needed to be analyzed; as discussed in later sections. However, theoretically, we say that WMN being a superset of adhoc network, protocols and QoS solution should work for WMN too. Our research work is to check practically this phenomenon on overlapping wireless mesh networks whether existing solutions are feasible for overlapped scenario as work for single networks or there is a need for developing separate solutions for overlapped and multichannel networks.

1.7 Thesis Outline

Chapter 2 contains the brief survey of existing technologies and literature related to our research area. Also the important findings from literature and limitations in the existing literature are described in chapter 2. The focus of chapter 3 is on problem domain. Chapter 4 gives the detail about proposed solution and design of system. Implementation details and simulation results are describe in chapter 5. Chapter 6 contains the concluding remarks, contribution of research work and suggestions for future research work.

Chapter No 2

LITERATURE SURVEY

2.1 Introduction

Most of the applications using in internet are real time in nature with different service requirements. The mode of operation of wired and wireless is different but user expectations from both networks are same. To fulfil their demands wireless networks must be capable to carry out the needs of multimedia applications to give improved quality of services to users. In this chapter a brief survey of existing technologies and literature related to our research area is given. Also the important findings extracted from literature and limitations in the existing literature are described.

This chapter contains five sections. In Section 2.2 related literature study related to the research topic is given. After reviewing the literature, some important findings are obtained which are arranged in the form of table in section 2.3. Section 2.4 is related to the limitations of the literature investigate in previous section. Lastly, section 2.5 contains summary of the whole chapter.

2.2 Related Research/Technologies

2.2.1 Need for QoS in WMN

The major and important issue which should be considered and handled efficiently in networking is Quality of Service and is very challenging in case of wireless and mobile networks. Reliable network performance was important in networks for many applications but provisioning of QoS become more important with the development of multimedia applications and with an increased real time transmission on networks [37]. Different applications have different service requirement and they need differential treatment. Due to this very reason, QoS is also very essential in WMN to support real time traffic, mission critical applications, for providing broadband internet access etc [12, 18]. QoS guarantees are important and challenging task in wireless networks. As wireless networks have limitations in terms of bandwidth, capacity and unpredictable node movement which can't be controlled. WMN is also a wireless network and has the same problems [12, 15]. QoS is very challenging and necessary in WMN. The reception and arrival of data for multimedia application should be very fast otherwise their quality will be suffered due to continuous interruptions [42]. QoS is the measure of level of service availability and transmission quality of network in terms of latency, jitter, and loss [36].

Different applications have different requirements to reach a certain level. Voice and video both are sensitive to delay but voice applications are more sensitive to packet loss as compared to video. Video traffic can afford packet loss to some extent but cannot afford delay, as the arrival of packets in sequence at the destination is vital. On the other hand, data traffic can afford delay but sensitive to packet loss. Mission critical applications are both sensitive to delay and packet loss. So to fulfill all these requirements, WMNs need strong QoS guarantees [26].

Finding No.1: For handling and satisfying varying service requirements of real time and multimedia applications, QoS is necessary in WMN.

2.2.2 Challenges to QoS in WMN

QoS provisioning is very hard task in WMN as compared to wired networks, because wired networks have stable topology, a central controlling entity and limited to a particular and small area. Hence, provisioning of QoS is not difficult. WMN and other wireless networks have nodes which are mobile which cannot be detected in advance. There is no central authority which controls all the activities of network. Communication between nodes in WMN requires multi hop with limited battery power of clients [12].

Since in current WMN there is no intermediate control, so when network size grows, the problem of scalability arises. Also QoS provisioning for different types of applications from source to destination become very difficult due to multi hop communication and node mobility and is still a challenge [16]. WMN is a relatively new field and is growing day by day and facing many challenges. A lot of research is done for QoS provisioning in WMN like QoS routing, cross layer designs etc. Nevertheless there is not a complete solution or algorithm for QoS. It is still using protocols and QoS solutions of adhoc network [26].

Finding No.2: QoS is very challenging problem in WMN due to random node movement, wireless multi-hop communication, distributed architecture etc.

2.2.3 Cross Layer Designs for QoS in WMN

Cross layer designs are developed in WMN for QoS provisioning in different layers. The real world implementations of cross layer design creates many problems for researchers which will be critical. It is quite sophisticated task, as multiple protocols belonging to various layers need to be changed first as per the requirements and later additional modules need to be added to bypass the typical flow of the protocol stack. Stable communication and coordination between network having cross layer designs is difficult. Any change or improvement made at any layer, have to accommodate this change in all layers. This problem limits the use of cross layer designs [17].

Even though, cross layer approach has its advantages, so are its problems. If cross layer designs are not maintained properly and in sequence, code optimization is not possible and hence may result in replication of functionalities. These designs require the functionality to be reflected in all layers, so should be simple and very clear [19, 29]. Cross layer designs are not necessary to be a perfect solution in WMN. WMNs have characteristics of adhoc like continuously changing topology of WMN due to failure of any link and movement of node. This constant variation in topology of WMN effects on different protocols layers. For protocol improvement cross layer designs can work but have many open issues [42].

Finding No.3: Cross layer designs are using for QoS in WMN but have many problems and are not a complete solution for QoS and performance of WMN.

2.2.4 Architectural Differences between WMN and MANET

WMN is taken as enhance form of Adhoc because both are wireless networks and having same feature like capacity limitations and link variability, wireless multihop communications, conflict for getting right to use channel, distributed architecture etc [12, 15]. When adhoc network techniques are used by WMN additional capabilities, design principles and techniques are required. WMN improve the potential of adhoc and can be thought of multihop Mobile Adhoc Networks (MANET) with extended connectivity and additional capabilities [14]. Both are multihop, self-creating, self-organizing, self-administrating networks and have mobile clients and distributed architecture. In adhoc network, nodes use wireless medium and are possibly mobile whereas in WMN some nodes are mobile and remaining are fixed.

Adhoc network may or may not rely on infrastructure whereas WMN definitely requires infrastructure to operate. In WMN most traffic is user-to-gateway where in adhoc network most traffic is user-to-user or peer-to-peer in nature [38, 42]. The coverage area of WMN is larger due to its wireless backbone where different networks can attach and offer increased connectivity where in adhoc network the network stability is the responsibility of end user and may not provide trustworthiness. In WMN mesh clients are accountable for routing and organizational functions where in adhoc again end user have to do so, this thing put extra burden on them. Due to these reasons network employment and routing protocols may be become complicated [42].

Finding No.4: MANET and WMN are type of Wireless Ad-hoc Network and have many things common. Due to this reason MANET QoS solutions can be use in WMN.

2.2.5 MANET QoS Models

There are different QoS models for MANET i.e. dQoS, FQMM, INSIGNIA , HQMM, SWAN, ESWAN etc. dQoS (dynamic Quality of Service) and INSIGNIA fall into category of stateful models. dQoS can be considered as extended form of integrated services which is QoS model for wired networks. It is an old model of MANET which makes few changes in fixed domain QoS model and hence suffers from same problem of scalability. It uses the typical reservation protocol of integrated service RSVP by making simple changes in it to handle dynamically a large no of resource reservations of different flows. dQoS model deals with the changing bandwidth and its requirements in wireless mobile network. It fairness tenet has some problems and is also questionable [43, 53].

INSIGNIA which is a competent proposal for light weight in-band signaling and it work well with changing network topology and different constraints. In INSIGNIA when a flow travel from source to destination all nodes involve in communications have same per flow states. When movement of clients increases in INSIGNIA the no of flows and performance decreases. It is a stateful model and required that all nodes should be synchronized and maintains states about network and routes and nodes, hence not scalable [29, 43]. FQMM and HQMM are hybrid QoS models which combine the functionalities of others models and enhance them. FQMM (Flexible Quality of Service Model) merge class based routing of differentiated services with flow based routing of integrated services. FQMM use DiffServ for few types of traffic flows otherwise for all other types it uses integrated services and also not scalable [43, 53]. HQMM (Hybrid Quality of service Model) QoS model merge the class based routing of differentiated services with flow based routing of INSIGNIA. HQMM shows flexibility in provisioning QoS and is a scalable model. In HQMM with an increased in the mobility of nodes and topology changes frequently, overall performance of network decreases gradually. The proportion of packet delivery and performance is decreased due to lack of understanding among different INSIGNIA based flows especially when network size grows and distance between source-to-destination increases in terms of no of hops [31, 43].

Finding No.5: dQoS, FQMM, INSIGNIA, HQMM QoS models are not selected because these have many problems and are not adequate for our work.

2.2.6 SWAN QoS Model

SWAN is a stateless network QoS model which uses distributed control algorithms. The SWAN model includes a number of mechanisms used to support rate regulation of best-effort (BE) traffic and admission control regulation of real-time (RT) traffic. Being a stateless model synchronization of nodes or any other complex signaling techniques are not required in SWAN and ESWAN. To handle congestion due to overloading or unpredictable movement of nodes, SWAN incorporates ECN mechanism and placing ecn bit in IP header [53, 55]. By using this mechanism flows are re-initiated and regulated in congestion by sources in response to destination regulate message. The working of SWAN is smooth and reliable and is not affected by any change in network conditions or due to failure of any node or link.

SWAN quickly recovered efficiency of real time flows that was affected in congestion phase by introducing source and network based regulation where ESWAN also incorporates destination based regulation to improve recovery process [43, 50]. SWAN has no concern with underlying routing protocol and does not change the routing and with any reactive or proactive protocols SWAN can work efficiently [6]. SWAN uses delay experienced by packets when transmitting at MAC layer as response. For real time traffic admission control mechanism at sources is used where rate of best effort traffic is controlled by each node using AIMD algorithms to provide more space and bandwidth to real time flows and improve their performance. This thing keeps the traffic load and working of SWAN smooth and results in reduction of buffer load and sizes of queue [43, 55].

Finding No.6: SWAN enhanced to ESWAN, is the most promising and advanced model among all other MANET QoS models due to its unique features.

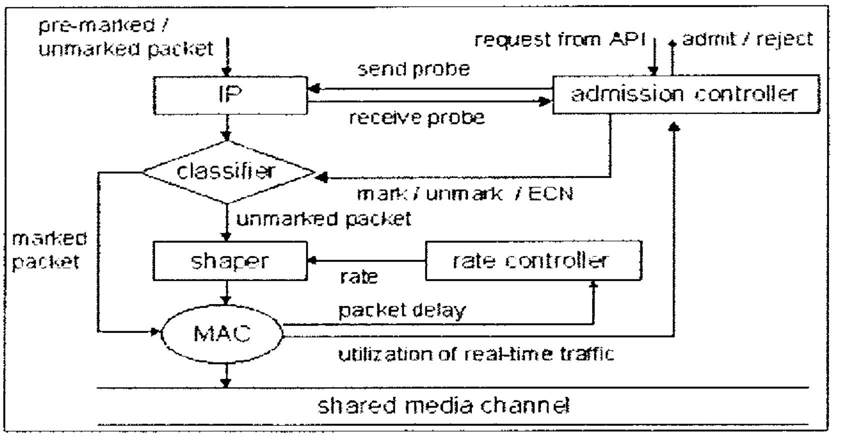

Figure 2.1: SWAN QoS Model Architecture [55]

2.2.7 Overlapping Problem in Wireless Networks

The phenomenon of overlapping networks can be defined as" the networks whose service area got overlap and have many AP's belonging to both networks" [3]. When two or more networks exist in the neighborhood of one another, the boundaries cannot be outlined and thus may get overlapped resulting in a geographical area where AP's of both networks occur. When networks get overlapped in a service area and there is no form of communication between them, then serious problems arise due to this overlapping. Interference issue arises due to existence of multiple wireless networks in one area without coordination. This interference among nodes effect the performance of multi-hop wireless networks [13]. The interference issue does not allow us to use multiple radios. We are limited to use only few radios which will affect performance and capacity of networks. The main problem due to transmission on overlapping channels is interfernce which is an unavoidable problem in wireless networks. Communication on their neighboring nodes or channel is also effected by this interference and is called adjacent channel interference [44, 45].

Due to overlapping networks, problems in logging into network by using VPN arise although connection setup has no problem and is successful. This occcur when networks of two different organizations overlap and router of one network assign address which match with 2nd network any machine. In NAT overlapping occur when two organizations combine and may use same addressing scheme, false assignment of a address of a particular company to another company and result is two companies using same addresses. In all these situations NAT cant differenciate between public and private addresses and cant tell whether destination is within the network or outside [46].

If two networks become overlap in a service area and there is no form of communication between these networks, there will be a significant decrease in their performance and throughput [20, 23]. If two networks overlap and single common channel is used for communication among multiple cells of networks. Then flow of traffic to one destination will effect other neighboring destinations and creat collision on channel and will disrupt flows to other destinations [2].

Finding No.7: Overlapping of multiple networks with multiple AP's in one service area, having no inter-domain traffic cause serious problems and is an open issue.

2.2.8 Overlapping Wireless Mesh Networks

Using extra routers and access points will have major effect on coverage on WMN and it will be significantly improved but these extra routers can increase total length of routing path, so more resources will be needed which will reduce the performance and throughput of WMN. Unplanned development of Wireless mesh networks (WMNs) by different organizations may result in partial or complete overlapping of these networks and as a result multiple access points present in one service area which will lead to interference among nodes and decrease performance. This channel interference cause collisions and reduced the throughput of WMN [20, 42]. The unplanned deployment of multiple WMNs by multiple people cause resource node contention problem which affect the capacity and overall performance of network [30]. Different issues affect the performance and reduce the capacity of WMNs overlap in one service area. These problems include link congestion which occurs when adjacent nodes face interference and links having more traffic which is caused by multiple continuous traffic etc [5].

Finding No.8: Unplanned deployment of WMNs by multiple authorities results in overlapping and cause problems of congestion, interference and capacity reduction.

2.2.9 Impact of Overlapping Channels in Wireless Networks

When large amount of data is to be transmitted on different channels, use of small no of non-overlapping channels significantly reduce performance. By use of multi channels not only performance and throughput can be improved but also there will be less interference and more capacity and channels for users. When channels get overlap there is greater chance of interference but by setting the transmission power of nodes cautiously will have positive effect on real time. A constrained optimization problem is formulated and heuristic algorithm is design for make use of overlapping channels for different data flows and keeping transmission power of every node at one level this will result better in terms of higher performance of real time and low power consumption as compared to only using few orthogonal channels [1].

Combination of partially overlapping channels with non overlapping channels can fully utilize the limited resources of channels. Little work for assigning channel status to overlapping channels has been done. In [11] the issue of interference and its effect on wireless link is highlighted by using different existing graphs and propose a genetic algorithm to make use of overlapping channels by assigning them responsibilities. This approach use limited network resources and obtain better results in terms of interference, throughput and capacity.

Many research efforts are done to make use of these overlapping channels to enhance performance, throughput and avoid their wastage. One way is to use partially overlapping channels with non- overlapping channels for communication instead of completely overlapping channels to fulfill the requirements of networks. Than instead of reduction in throughput, capacity and interference there will be only minimum overhead of traffic collisions [24]. Partially overlapping channels can be used for enhancement of network performance [25]. Optimization is performed on end-to-end requirement of different flows instead of total sum of link capacity.

Finding No.9 Use of partially overlapping channels with non- overlapping channels increase performance, throughput and capacity of network and cause less interference.

2.2.10 Impact of Multiple Channels in Wireless Network

Multi-channels are very useful in terms of enhancing throughput and are found quite efficient under certain security attacks, like jamming attack. To avoid from jamming attack legitimate nodes leave the jammed channel and switch to new channel; either pre-determined or coordinated later [4]. There is one control channel and many data channels. Nodes switch to control channel to agree on one channel for communication and then switch to new channel, transfer data and switch to their original channels.

A jammer can abrupt one channel at a time, but simultaneous communication on different channels are prevented this way. In sensor networks when nodes operate on multichannel, their connectivity can be maintained in presence of interference by two techniques i.e. coordinated channel switching in which whole network shifted to next channel to maintain connectivity and 2^{nd} one is spectral multiplexing in which only nodes in jammed area switch channels and act as a bridge between different channel area. These techniques make it easy to repair network without significant overhead even if there is interference [27].

Single channel decrease the capacity of multihop networks. By using multichannel we can improve network capacity by channel switching. The concept of channelization was added to 802.11 standards to avoid interference among nodes by keeping the APs at different channels. In Slotted Seeded Channel Hoping (SSCH) nodes remain on a particular channel for 10ms and switch channel to communicate with neighboring nodes which are at different channels [54].

Finding No.10: Performance and capacity of wireless networks can be improved by using multi channels and switching between them.

2.2.11 Interworking in Overlapping Wireless Networks

When multiple WMNs become overlap and if there is no interactions and communication among multiple domains in overlap, this thing will cause interference among individual mesh networks and reduce their throughput and capacity. Therefore, it becomes necessary to define some nodes in overlapped area as bridge nodes and allow multiple wireless mesh networks to coordinate and communicate by using bridge nodes. Interworking means both overlapping domains should communicate and interact with one another and allow each other traffic to pass through them by means of bridge nodes. It is very necessary to coordinate these by providing inter-networking in these overlapping networks. By this way overall performance as well as performance and throughput of individual networks will be considerably enhance [20]. Different authors work on interworking of wireless networks.

In [23] authors have talk about issues related to performance of WMNs, in the situation when Wireless mesh networks (WMNs) are deployed unintentionally by multiple organizations in one area which cause partial or complete overlapping of these networks, resulting in contention of radio resources among them. They provide coordination among networks by means of BNs.They move from partially overlapped networks to complete overlapped and varying the number of BNs randomly to find the optimal number of bridge nodes at which system throughput / throughput of both networks is maximum. They show Impact of BN selection and importance in controlling network unfairness. They consider one hop scenario to reach destination and use bridge nodes for this purpose. And bridge nodes are equipped with multiple radios and they also act as sources.

The use of Local Area Networks is increasing day by day in our daily life. In [32] develop methods for service discovery, session management, and security support for seamless service interworking in ad-hoc networks. They develop a security module name AA module for authorization and authentication of users to run/execute communication in secure mode. Their major concern was security and nodes have to authenticate each other before communication by base key pair stored in AA module.

In [7] authors have worked on throughput optimization approach to model the unplanned wireless mesh networks (WMNs) deployment problem based on partitioning hierarchical cluster (PHC) based architecture, and using bridge nodes to allow interworking traffic between overlapping WMNs to reduce the performance degradation. The solution contain node model, connection model, interference model and cluster model. WMNs can be divided into multiple disjoint hierarchical clusters, partitioned into several Gateways (GW) domains for interworking these networks. The bridge nodes are selected more accurately after clustering. While maximizing the total network capacity by interworking multiple wireless mesh networks, key constraint is to limit the number of bridge nodes.

Finding No.12: Proper interworking in overlapping wireless networks is very necessary and will significantly improve performance and throughput of these networks.

2.2.12 QoS in Overlapping Wireless Mesh Networks

When multiple WMNs become overlap and if there is no interactions and communication among multiple domains in overlap, this thing will cause interference among individual mesh networks and reduce their throughput and capacity [23].

In [20] authors have talk about issues related to performance of WMNs, in the situation when Wireless mesh networks (WMNs) are deployed unintentionally by multiple organizations in one area which cause partial or complete overlapping of these networks. This thing result in different access points belonging to different networks occur in one service area which arise conflict among nodes for accessing network resources and interference among adjacent nodes. LP formulation of the scenario is done and also they show the effect of bridge node selection.

In [7] author's effort was on solving the unplanned wireless mesh networks (WMNs) deployment problem using bridge nodes to permit inter-networking traffic between overlapping WMNs to minimize the performance reduction.

Finding No.12: No research effort have been made for QoS provisioning and handling of congestion on bridge nodes when WMNs become overlap in a service area.

2.3 Findings Extracted from Literature Survey

We get some important points and findings after reviewing the related research and literature which are summarize in the following table to get a quick overview of literature, problem domain and need of solution. We studied why QoS is important and challenging in WMN, what are the present and existing solutions for QoS in simple and overlapping WMN, comparison of WMN with adhoc, overlapping wireless mesh networks, their problems, need for coordination bridge nodes, multi channel and requirement of QoS in overlapping WMN etc.

We review existing literature in depth in concept-wise. And after every concept we make some finding on the basis of literature studied which are summarized in table 2.1.

Table 2.1: List of Findings Extracted From Literature Survey

S. no	Findings	Justification	Refer:
1.	For handling and satisfying varying service requirements of real time and multimedia applications. QoS is necessary in WMN.	• Out of Sequence Packet Arrival • Packet Loss • Real time Filters	12, 15, 18, 26, 36, 37, 42, 42
2.	QoS is very challenging problem in wireless networks to support varying requirements of real time and multimedia application especially in Wireless Mesh Networks.	• Random node mobility • Multi-hop communication • Lack of centralized control.	12, 16, 26
3.	Cross layer designs are using for QoS in WMN but have many problems and are not a complete solution for QoS and performance of WMN.	• Change->each device • Maintenance difficult • Hard to optimize	17, 19, 29, 42
4.	MANET and WMN are type of Wireless Ad-hoc Network and have many things common. Due to this reason MANET QoS solutions can be use in WMN.	• Dynamic topology • Distributed architecture • Channel access Contention	12, 14, 15, 38, 40
5.	dQoS, FQMM, INSIGNIA, HQMM QoS models are not selected because these have many problems and are not adequate for our work.	• Stateful models • Mostly extension of fixed domain models	31, 29, 43, 53
6.	SWAN enhanced to ESWAN, is the most promising and advanced model among all other MANET QoS models due to its unique features.	• Stateless • Routing independent • Destination based	6, 43, 50, 53, 55
7.	Overlapping of networks with multiple AP's in one service area, having no inter-domain traffic cause serious problems and is an open issue.	• Interference among neighboring nodes • Collision • Capacity Reduction	2, 3, 13 20, 23,44, 45, 46,
8.	Unplanned deployment of WMNs by multiple authorities results in overlapping of networks and cause many problems.	• Performance degradation of individual WMN. • Interference • Collision	5,20, 30, 42
9.	Use of partially overlapping channels with non-overlapping channels in wireless networks are very useful and have many benefits.	• Increase performance • Throughput • Less interference	1, 11, 24, 25
10.	Performance and capacity of wireless networks can be improved by using multi channels and switching between them.	• Increase Performance • Increase Capacity	4, 27, 54
11.	Proper interworking in overlapping wireless networks is very necessary and will significantly improve network behavior in different scenarios.	• Improved Performance • Increase Capacity • Coordination among networks	7, 20, 23, 32
12.	No research efforts have been made for QoS provisioning and handling of congestion on bridge nodes when WMNs become overlap in a service area.	Research efforts are on • Bridge nodes selection • Security	7, 20, 23

2.4 Limitations

After reviewing the existing literature it is found that QoS guarantees are very important in WMN due to its unique features and to support audio and video communication and to satisfy varying necessities of these applications. WMN is an emerging field and there is little work for QoS support in it. Cross layer designs for WMN are developed but they still have many problems and are not a complete QoS solution. There is not yet any QoS model developed for WMN. WMN still using protocol and QoS solutions of Ad hoc network as both are types of Wireless Ad-hoc Network.

When individual WMNs become overlap and if there is no coordination in Overlapping wireless mesh networks, their capacity, performance and throughput will be decreased. So proper interworking of these overlapping WMNs by mean of bridge nodes is very necessary. There are only few research efforts on interworking which are not complete and they work on few aspects of overlapping networks. In [32] only peer-to-peer adhoc network is considered and solution is applicable to only small scale networks. They didn't consider multihop networks.

Authors in [23] provide coordination by BNs but optimal bridge nodes selection without varying traffic loads. No traffic types and load is discussed. They consider network throughput only in terms of bridge nodes selection not as QoS. Coordination in overlapping networks is also provided by BNs in [7] but no criteria for BNs selection after clustering and they also considered networks throughput in –terms of BNs selection and shorter paths not as QoS.

After reviewing literature we find that multihop scenario in overlapping WMNs is not yet considered. Also the working and behavior of BNs with varying traffic types and varying traffic loads is not being analyzed. There is no proper formula for BNs selection and for their dynamic configuration in existing literature. Also there is no work on QoS of overlapping wireless mesh networks. No research effort to handle congestion and minimizing packet drop on bridge nodes , showing behavior of bridge nodes in different scenarios and QoS provisioning in these overlapping WMNs.

2.5 Summary

In this chapter we studied and properly review the existing research work, technologies and literature related to our problem domain to clearly show our problem area and need for the solution. Then we summarize the important findings and points in the form of table which we concluded from the literature survey to give a quick overview. In the end we state all the problems and limitations of the existing research technologies and solutions and show the need of our research work and solution.

Chapter No 3

PROBLEM DOMAIN

3.1 Introduction

Nowadays wireless networks are commonly used and mostly preferred on wired networks as these networks do not require extensive cabling and are faster, reliable, easy to use and less costly. With the time multimedia applications arise and get important position among different wireless networks. Multimedia applications are different from best effort and required different level of services. Provisioning of QoS to such applications is very difficult and expensive in wireless mesh network due to limitations of wireless networks and varied requirements of these applications. When we are using and handling real time and multimedia applications in our network, the quality of service parameters which must be taken into consideration are bandwidth usage, rate of packet loss and management of congestion.

This chapter focus on research problem domain and objective of thesis. Section 3.2 discusses QoS approaches for fixed networks. Section 3.3 describes QoS models for adhoc networks. Section 3.4 describes different multichannel MAC protocols in wireless networks. Section 3.5 contains the problem scenarios of WMN. Section 3.6 defines the problem statement. Section 3.7 shows the focus of our research. Section 3.8 contain summary of whole chapter.

3.2 Fixed Domain QoS models

There are QoS solutions which are for fixed topology networks whose all nodes are static and architecture is fixed. Following are the fixed domain QoS models:

3.2.1 Integrated Services (IntServ/RSVP)

In IntServ [52] flows arrive at sources and sources pass their QoS requirements to destination and routers on different routing paths through signaling protocol RSVP and dRSVP, So that both the destination and routers occurring on routing path should aware of their QoS needs. RsVP is used to make reservations on routers for different flows and each router maintain states for resources reservation. Along with best effort service, IntServ provide Guaranteed Service and Controlled Load Service. The former class is handling applications which can't afford where latter class is for flows which require more reliability then best effort. It is not suitable in MANET due to following reasons:

- Large amount of bandwidth consumption due to signaling protocol reservation
- Not scalable due to states maintained at each router result in heavy storage capabilities requirements and overhead of processing.
- Mobile hosts are power and resource constraint, hence process of admission control, classification and scheduling of packets cause huge load for these.

3.2.2 Differentiated Services (DiffServ)

The problem of scalability is solved by differentiated Service (DiffServ) [39] as it describe a set of behaviors known as Per Hop Behaviors (PHB), for routing flows and associate it with edge routers. A special field known as DSCP is put in the IP header of packets which define their respective per hop behaviors for routing them in network. The routers inside the domains check the IP header for getting information about PHB of flows to forward them.by this way flows are divided into different service classes according to their importance and services requirements to attain a level of quality. DiffServ solve scalability problem to some extent but due to lack of provisioning QoS guarantees to flows on end-to-end basis, is not a perfect solution for MANET and internet. Use of DiffServ in MANET may be possible but require modifications, because it shift the complexities to boundary routers. The problems related to DiffServ which limits its use in wireless networks, are given in the following:

- Tracing and marking routers as as boundary and interior in wireless networks is quite complicated task.
- The DiffServ and internet use the terminology of Service Level Agreement (SLA) which is necessary for their working but it is not present in MANET.

3.3 QoS models for Ad hoc network:

There are different QoS models for adhoc networks. They can be divided into stateless, stateful and hybrid models. A brief detail of these models is given below:

3.3.1 Stateless QoS Models

The category of stateless models includes SWAN and ESWAN. Being a stateless model synchronization of nodes or any other complex signaling techniques are not required in SWAN and ESWAN. To handle congestion due to overloading or unpredictable movement of nodes, SWAN incorporates ECN mechanism and placing ecn bit in IP header [43, 53, 55]. By using this mechanism flows are re-initiated and regulated in congestion by sources in response to destination regulate message. The working of SWAN is smooth and reliable and is not affected by any change in network conditions or due to failure of any node or link. SWAN quickly recovered efficiency of real time flows that was affected in congestion phase by introducing source and network based regulation where ESWAN also incorporates destination based regulation to improve recovery process [43, 50].

3.3.2 Stateful QoS Models

dQoS (dynamic Quality of Service) and INSIGNIA fall into this category. dQoS can be considered as extended form of integrated services which is QoS model for wired networks. It is an old model of MANET which make few changes in fixed domain QoS model and hence suffer from same problem of scalability. It uses the typical reservation protocol of integrated service RSVP by making simple changes in it to handled dynamically a large no of resource reservations of different flows. dQoS model deals with the changing bandwidth and its requirements in wireless mobile network. It fairness tenet has some problems and is also not genuine [43, 53]. INSIGNIA which is a competent proposal for light weight in-band signaling and it work well with changing network topology and different constraints. In INSIGNIA when a flow travel from source to destination all nodes involve in communications have same per flow states. When movement of clients increases in INSIGNIA the no of flows and performance decreases. It is a stateful model and required that all nodes should be synchronized and maintains states about network and routes and nodes, hence not scalable [29, 43, 53].

3.3.3 Hybrid QoS Models

FQMM and HQMM are hybrid QoS models which combine the functionalities of others models and enhance them. FQMM (Flexible Quality of Service Model) merge class based routing of differentiated services with flow based routing of integrated services. FQMM use DiffServ for few types of traffic flows otherwise for all other types it uses integrated services and also not scalable [29, 43, 53]. HQMM (Hybrid Quality of service Model) QoS model merge the class based routing of differentiated services with flow based routing of INSIGNIA. HQMM shows flexibility in provisioning QoS and is a scalable model. In HQMM with an increased in the mobility of nodes and topology changes frequently, overall performance of network decreases gradually. The proportion of packet delivery and performance is decreased due to lack of understanding among different INSIGNIA based flows especially when network size grows and distance between source-to-destination increases in terms of no of hops [31, 29, 43].

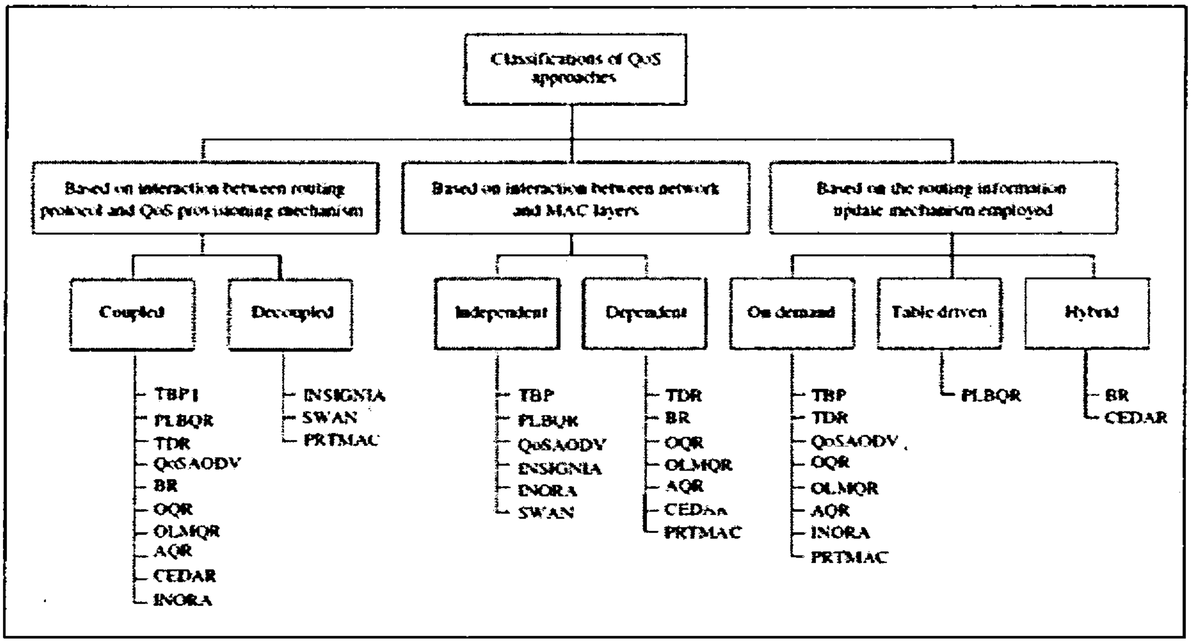

Figure 3.1: Classification of Adhoc QoS Approaches [53]

3.4 Multi Channel MAC Protocols

We provide a brief review in this section about different MAC protocols which are based on multi channels. These protocols are divided into four different types i.e. dedicated control channel, common hopping, split phase and parallel rendezvous [21]. The first three are single rendezvous protocols which uses single channel for exchange of control information where fourth one is multi rendezvous which uses multiple channels for exchange of control information. In all these protocols to carry RTS and CTS frames for making agreement in data transmission, time is divided into small periods.

3.4.1 Dedicated Control Channel

In this scheme each gadget is equipped with two radios. One radio is reserved for exchange of control information and always tune for control messages where second radio can listen to any channel at any time. When a device1 want to communicate with device2 it send RTS having the lowest no free channel, to control channel. When device2 receive RTS it send CTS to control channel that it is agreed for communication on specified channel suggested by device1. RTS and CTS contain the piece of time in NAV (Network Allocation Vector) to tell the other devices the duration during which both devices and specified channel are not available to other. All the devices know about status of all other devices and channels since they always listen to control channel. These protocols don't require synchronization as agreements are always made on a particular control channel but costly due to use of two radios. Examples of this scheme are Dynamic Channel Allocation (DCA), Dynamic Private Channel (DPC) etc.

3.4.2 Common Hopping

In this scheme devices used all channels for swapping of their data and have one radio. Two nodes after building contract for transmission of data, stop visiting channels. These devices make this contract after knowing the position of other devices. Only idle devices can sense channel where busy devices don't know about status of other. Channel Hopping Multiple Access (CHMA) and Channel Hopping Multiple Access with packet Trains (CHAT) fall into his category.

3.4.3 Split Phase

Split phase as name indicates time is partition into multiple control and data phases which come after one another. In control period, all devices having single radio listen to control channel and create contracts. Then data phase come in which devices switch to respective agreed channels and exchange data. Then again control phase and so on. MMAC and Multi channel Access Protocol (MAP) fall into his category

3.4.4 Parallel Rendezvous

In this scheme multiple devices make contracts for communication on different channels rather than using a single control channel for making agreements, like in above schemes and solve the problem of control channel being bottleneck. After this switch to multiple channels upon which they agreed to transfer their data. Slotted Seeded Channel Hopping and Multichannel MAC are the examples of this category.

3.5 Problem Statement

Unplanned deployment of Wireless mesh networks (WMNs) by multiple organizations may result in partial or complete overlapping of these networks and as a result different access points/routers/nodes belonging to different networks occur in one service area. When multiple WMNs become overlap and if there is no interactions and communication among multiple domains in overlap, this may cause interference among individual mesh networks which reduce their throughput and capacity. Therefore, it becomes necessary to define some nodes in overlapped area as bridge nodes and allow multiple wireless mesh networks to coordinate and communicate by using bridge nodes. Interworking means both overlapping domains should communicate and interact with one another and allow each other traffic to pass through them by means of bridge nodes. It is very necessary to coordinate these by providing inter-networking in these overlapping networks. By this way overall performance as well as performance and throughput of individual networks will be considerably enhance.

So need is to proper coordinate overlapping domains by BNs and consider multihop scenario in overlapping WMN [23, 32]. The working and behavior of bridge nodes with varying traffic loads and traffic types is need to be analyzed [7, 23]. A generic formula for BNs selection is to be developed for dynamic configuration of BNs which is applicable on any network. Since there will be few bridge nodes which will handle traffic of both domains so there will be congestion on these bridge nodes. So Quality of service guarantees in terms of congestion handling and minimizing packet loss on bridge node is very important. Because Quality of service is a factor which directly affect the overall working of a system should be handled properly [49]. Protocols of MANET are using in WMN as WMN is considered as a type of MANET with extended coverage and extra capabilities. So need is to analyze the feasibility of MANET QoS solution on overlapping WMNs to check its feasibility for two independent networks.

3.6 Focus of Research

The focus of research is to interlinked two overlapping wireless mesh networks, provide proper interworking between these networks by means of bridge nodes and investigate the feasibility of SWAN as an underlying model for provisioning of QoS. In our proposed solution we develop two wireless mesh networks which are partially overlapped in their service area and having nodes in this area termed as bridge nodes and coordinated by BNs. The destination of one network exists in the other network. Traffic of one network pass through bridge nodes and reach destination. Bridge nodes can be shared between networks or dedicated to their network. We select bridge nodes optimally not randomly. Because bridge nodes are few so should be selected carefully so they can handle traffic of both domains.

Through these bridge nodes traffic of one domain can pass to next domain and can pass through it. These bridge nodes will switch channels between both domains. As there are few bridge nodes so there will be congestion on these bridge nodes and packet will be dropped due to congestion which results in increase in delay and decrease of throughput. So to show effect of congestion on overall system and packet drop, we implement SWAN QoS model and check its feasibility for minimizing congestion and packet loss.

3.7 Summary

A detailed study about the QoS models of adhoc, different channel hopping techniques, our problem statement and focus of research is presented in this chapter. Overlapping wireless mesh networks, proper coordination among these and bridge node selection is an active research area, which still has quite many issues to address. Quality of service guarantees is one such region which also lacks in wireless mesh networks (WMNs) because WMN is a wireless network and has same limitations of wireless networking like limitations of bandwidth and capacity. QoS is very expensive task and also very challenging in WMN to fulfill varying service requirements of real time and multimedia.

Among the already discussed limitations of the recent studies and the efforts in provisioning of QoS standardization, the proposed solution can address one of overlapping wireless mesh networks by bridge nodes to interwork, select bridge nodes optimally, analyze behavior of bridge nodes in different conditions, etc. Theoretically speaking, inter-communication between different networks can be achieved at some cost (delay, packet drops, etc.). Similarly, the role of bridge nodes need to be optimized, especially when the networks are operating on different channels, thus channel hopping delay is estimated. Hence, the need of QoS is utmost. However, we can incorporate an existing QoS model like SWAN and tailor it accordingly by analyzing the behavior of varying network parameters and thresholds; if exist.

Chapter No 4

PROPOSED SOLUTION

4.1 Introduction

In design phase the architecture of proposed solution is developed. Basic design requirements and parameters of the proposed system are identified. In this phase we streamline a system architecture that initially explores the possible scenarios and later best feasible one is determined, theoretically. This phase provides an idea about the major players of the system and the functionality between them to be implemented. Generally, in design of system, we show how our system after design will be looked and present different scenario that how the system will work after its implementation.

The basic design requirements are described in section 4.2. Section 4.3 and 4.4 contain the detail of proposed architecture and methodology. Section 4.5 contains flow chart of proposed solution, section 4.6 contains UML diagrams and section 4.7 describes the summary of the chapter.

4.2 Design Requirements

The need is to develop two overlapping wireless mesh networks which are properly interlinked by bridge nodes to allow inter domain traffic and then implement SWAN model for QoS provisioning in overlapped wireless mesh networks. The focal points in this section are on the major entities like overlapping and interlinked wireless mesh networks, QoS parameters and bridge nodes which are the fundamental requirements of our proposed architecture. Furthermore, in view of real time and practical scenarios, scalability and deployment consideration of wireless mesh networks are also discussed.

a) Overlapping Interlinked Networks

Unplanned deployment of Wireless mesh networks (WMNs) by multiple organizations may result in partial or complete overlapping and as a result different access points/routers/nodes belonging to different networks occur in one service area [20]. If there is no form of inter-domain communication among multiple domains in overlap, this thing may cause interference among mesh networks in vicinity which reduce their throughput and capacity. It is very necessary to coordinate these networks by providing inter-networking in these overlapping networks via bridge nodes. By this way overall performance as well as performance and throughput of individual networks will be considerably enhanced. These interlinked networks will also require QoS to handle different types of traffic in multiple networks [23].

b) Quality of Service (QoS)

Quality of service is a factor which directly affects the overall working of a system and should be handled properly [49]. QoS include different parameters like network availability, packet drop, bandwidth, delay etc, varies from situation to situation. In proposed solution the performance metric taken for QoS is packet dropped due to congestion. As congestion has direct impact on network throughput and performance.

When there is more congestion, result is more packet drop and more re-transmissions, which consume more bandwidth. Result is bandwidth wastage and degraded Quality of service. So congestion should be handled efficiently to avoid packet drop and re-transmissions to save bandwidth and improve throughput. Also network availability in terms of bridge nodes availability is considered as if bridge nodes unavailable for short time result in packet dropped.

c) Bridge Nodes

When two or more wireless mesh networks become overlapped in a service area, the nodes occur in the overlapping area that entertain traffic forwarding on more than one networks, are called boundary or bridge nodes because they act as a bridge between two networks and make communication possible across the networks. So bridge nodes should be properly selected and handled [23].

d) Scalability

Military, emergency based applications require small wireless networks where commercial applications of wireless mesh networks require large scale deployment of these networks [36]. So these networks should be scalable, adjusting any additional nodes to increase coverage area and provide broad band internet access to commercial users at home, offices etc [37].

e) Deployment Considerations

There is distinction in deployment of wireless mesh networks [38] and wired networks because their behavior and architecture is totally different. These networks are self-organizing, self-configuring networks but proper planning is required to configure these networks because transmission range of certain nodes might overlap in service area without prior planning. So these networks should be designed to handle future growing traffic on any link in the network. The wireless mesh networks deployment has many benefits including low cost and short time of deployment, area of coverage, service availability, choice of protocol etc [41].

4.3 Reference Architecture

In our proposed solution we develop two wireless mesh networks partially overlapped with their own non-overlapped channels, having certain nodes in common area, termed as bridge nodes. For the sake of simplicity, both networks are homogenous in nature, for major parameters, like routing protocol, number of nodes, bridge nodes, etc. These networks require coordination among them which is provided by bridge nodes that act as connecting links between two domains. Since, the focus is inter-domain traffic and need is to apply QoS later, therefore the destination of one network exists in the other network. Traffic of one network passes through bridge nodes and reach destination. Bridge nodes can be shared between networks or dedicated to their network. As there are few bridge nodes so there will be congestion on these bridge nodes and packets will be dropped. In wireless networks packet loss or drop is due to three reasons mainly that include congestion on nodes, malicious node or error on channel [28].

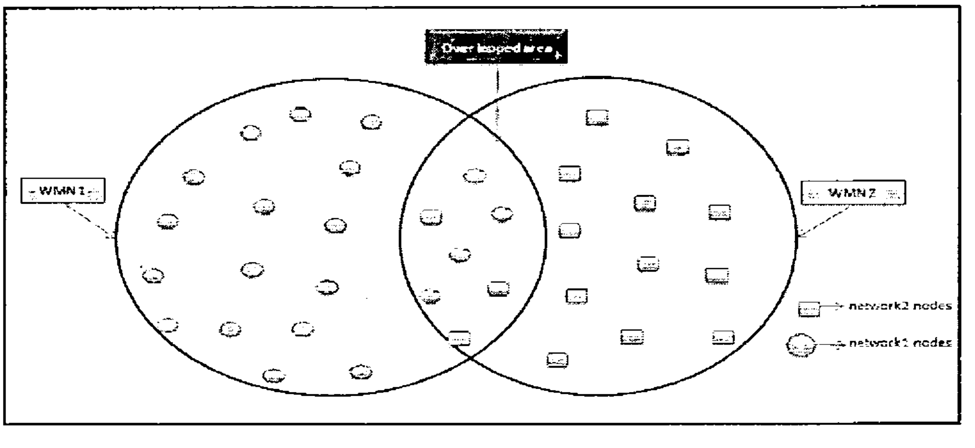

Fig. 4.1: Two Wireless Mesh Networks with Service Area Overlapped

So to show effect of congestion on overall system and packet drop, the need was to incorporate a QoS model initially, and which is to be tailored later in terms of the newer scenario. Thus, SWAN QoS model is applied and analyzed for its feasibility to minimize congestion and packet loss. As, both networks have their own channels. Single antenna having no intelligence is used, rather all intelligence is found at MAC layer; creating transparency in terms of routing protocol. Hence, our proposed solution can work with any routing protocol. For handling traffic of both networks in opposite directions, bidirectional links are used. 802.11b [8] an IEEE standard is used, which support three channels and fulfill our requirement. We develop a formula for bridge nodes i.e. 1 BN for every 4-Node but for the sake of redundancy we impose constraint that minimum 2-BNs in a network are necessary. Our research work is to check the feasibility of SWAN which is MANET model, on overlapped WMN whether feasible or not as WMN are considered as superset of MANET with extra capabilities and extended coverage.

4.4 Methodology

A particular process and specific steps are followed to find the solution of any problem. For the demonstration of proposed solution and generation of results simulation is performed. The environment use for simulation is OMNeT++ [47] and the basic architecture will be overlapping networks with bridge nodes and QoS model. The different possibility cases that can be used for evaluation and examination of the feasibility of our proposed solution are given in table4.1.

Table4.1: List of Different Scenarios/cases for Performance Evaluation

Bridge Nodes (BN)	**Traffic Flows**	**Testing and Evaluation Cases**	**Explanation**
Network Dedicated	No specification of traffic	**Case 1**: Network devoted bridge nodes forwarding traffic flows with no specification	-B.Ns are committed with their networks and entertains all types traffic flows including B.E and real times.
	Traffic specific	**Case 2**: bridge nodes devoted to their network and forward traffic flows explicitly	- BNs committed to their networks but one BN handle one type of traffic flows.
Shared Among Networks	No specification of traffic	**Case 3**: Bridge nodes common among networks. forwarding traffic flows with no specification	-all BNs serving both networks flows belonging to any traffic types.
	Traffic specific	**Case 4**: Bridge nodes common among networks, forwarding traffic flows explicitly.	- Both networks using all B.Ns but each B.N handle and entertain only one traffic type.

We analyze two cases in this chapter, for the proof of concept and understanding. In the following we are discussing two cases that are more generalized and by using any case performance of proposed solution will be evaluated.

4.4.1 Case-1 Network Dedicated Bridge Nodes with no Specification of Traffic

In this case the bridge nodes are committed to their own networks and entertain all types traffic flows including B.E and real times. Bridge nodes are serving for their individual networks. They can only receive packets from their own network directly. They can't receive the second network packets directly rather it can receive through 2nd networks bridge nodes. Each bridge node will switch to new channel only for the sake of forwarding their own traffic.

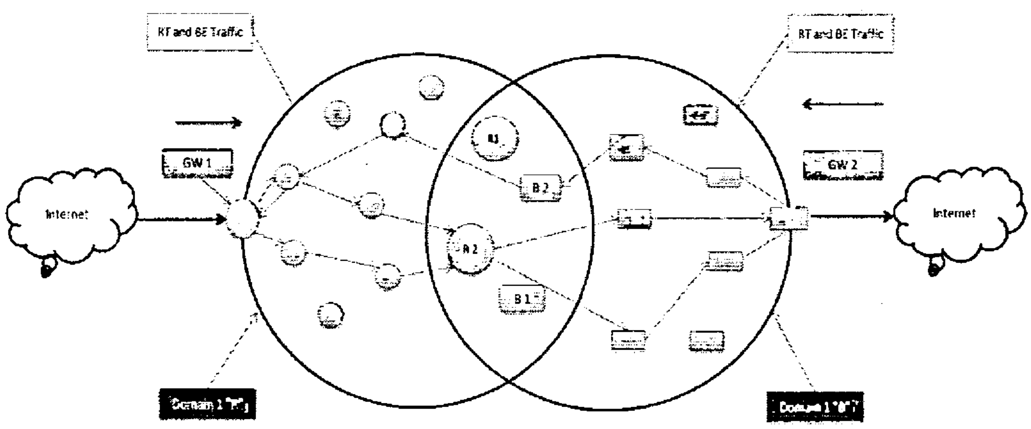

Fig. 4.2: Network Dedicated Bridge Nodes with no Specification of Traffic

In the above figure R1and R2 are the bridge nodes of domain1 and B1 and B2 are the bridge nodes of domain2. R1, R2 and B1, B2 serve for network1 and network2 respectively. Bridge nodes of both networks can communicate with one another i.e. R1, R2 and B1,B2 can communicate with one another and handle traffic flows of each other in case of load but any node in network 2 cannot send their data to R1 and R2 directly rather can send through their own bridge nodes B1 and B2 and vice versa.

4.4.2 Case-2 Network Shared Bridge Nodes with no Specification of Traffic

In this scenario both overlapping domains are completely shared and coordinated. All bridge nodes are common between both networks i.e. bridge nodes can receive and forward all types of traffic flows not only from their own network as well as the second network.

There is no specification and reservation of bridge nodes for a particular traffic type like audio, video, web, FTP etc. Bridge nodes will switch channels for forwarding both networks traffic. Any nearby bridge node can be located and selected by all nodes for forwarding their packets. bridge nodes will not only switch channels for their own networks, also for other networks traffic. Any bridge node of both networks can directly receive and entertain second network traffic flows.

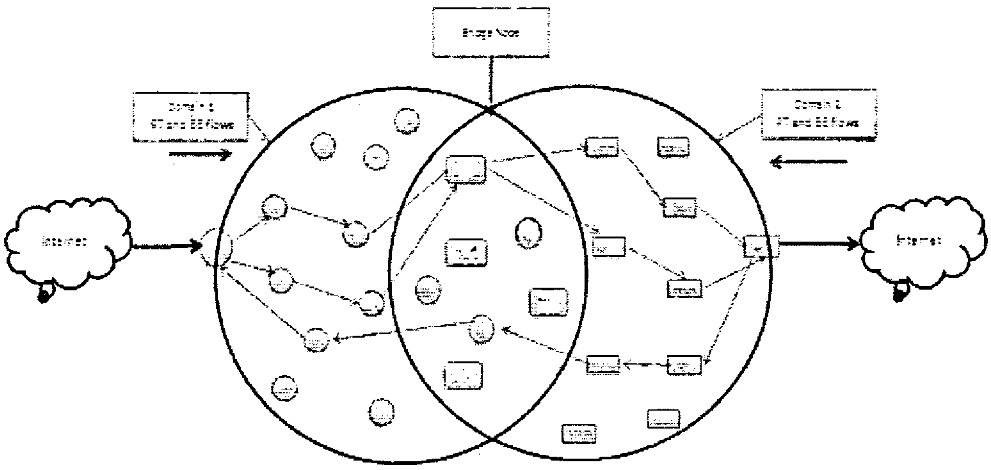

Fig. 4.3: Network Shared Bridge Nodes with no Specification of Traffic

4.5 Flow Charts

Flow charts show the flow of events in the system. In the following we draw the flow chart of our proposed architecture which describes how our system will work. In start networks and routing paths are established. Then networks adopt channels and nodes identify themselves as sources, sink and bridge nodes. Nodes originate packets and forward to next hop through MAC layer CSMA/CA mechanism in DCF mode by RTS, CTS exchange.

Nodes locate bridge nodes by RTS. If receive CTS before time out, then send packet(s) to bridge nodes otherwise back off and retry. Bridge nodes switch to new channel and locate next hop by RTS. If got response, send packets to next hop and in this way packets are reached at sinks. Dedicated bridge nodes receive interim ACK and switch back to original network where shared bridge switch channel when they receive not only interim ACK but also other network data packets.

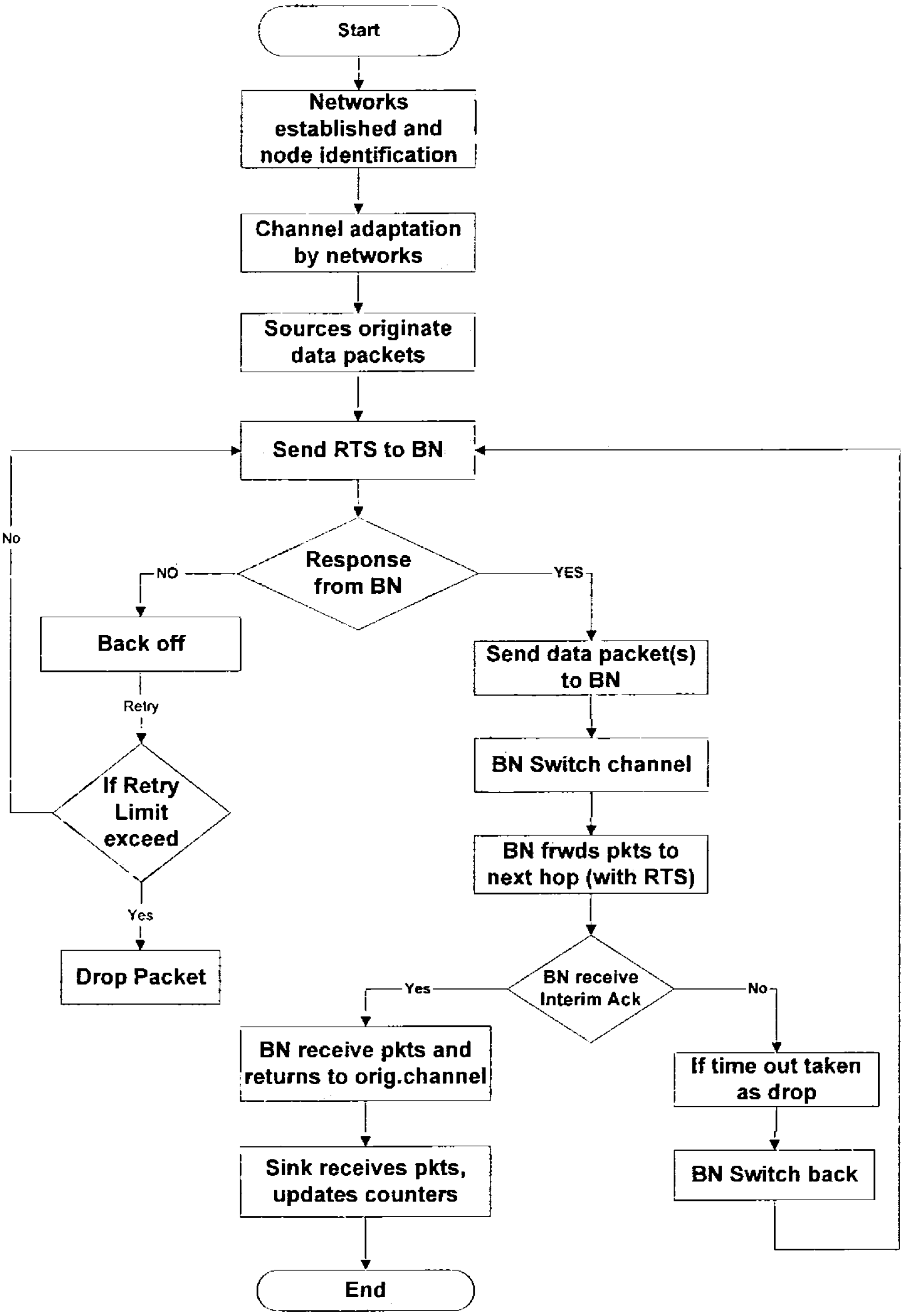

Figure 4.4: Flow Chart of Proposed Architecture

4.6 UML Diagrams

UML [48] is the abbreviation of "Unified Modeling Language". It is a graphical language which is used to show the design of proposed system by different ways using different diagrams including Use Case Diagram, Class Diagram and Sequence Diagram etc. Basically this is used by software system designers to specify and design their different system tools and simplify the complicated process of designing a software system.

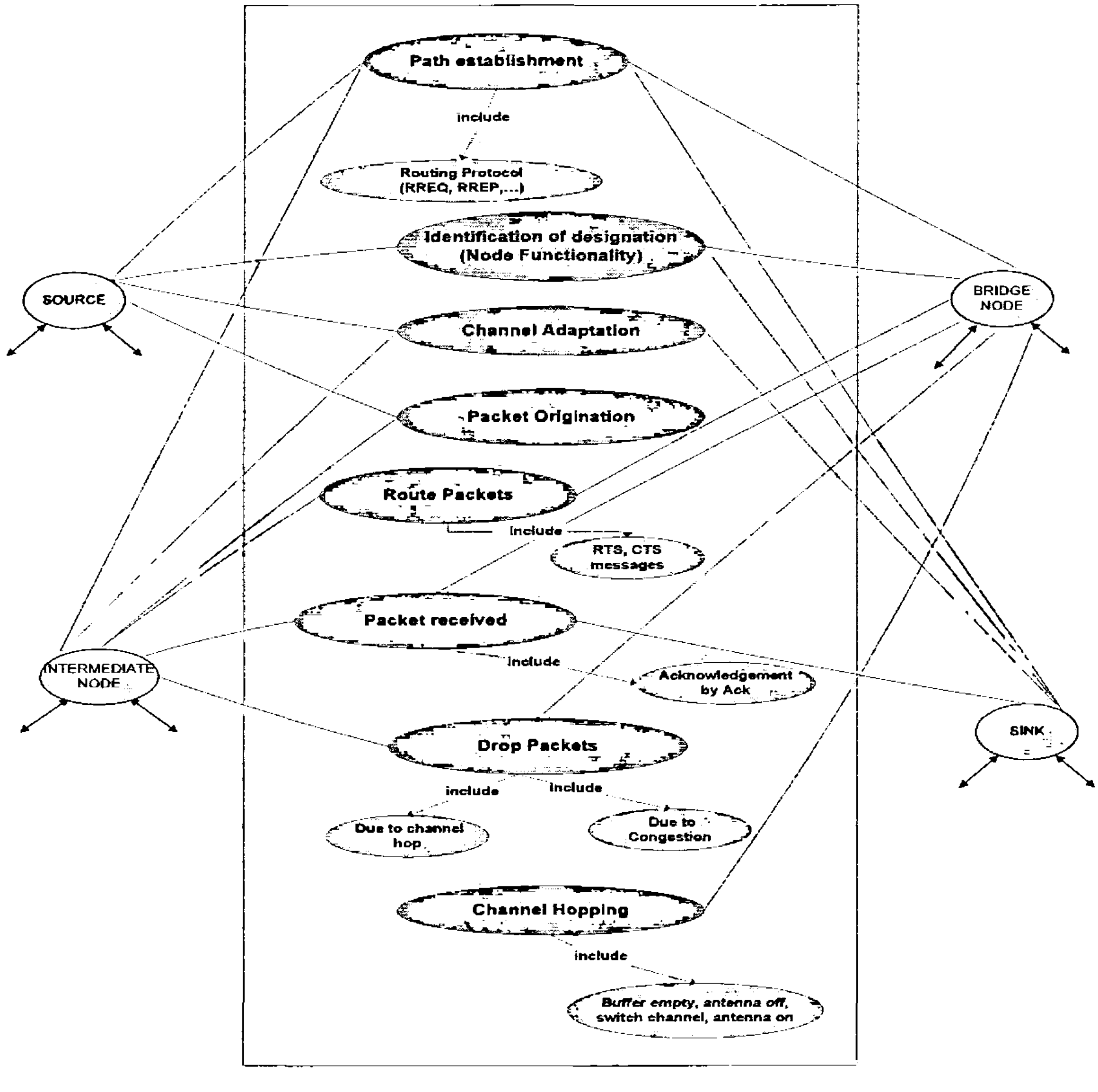

Figure 4.5: Use Case Diagram

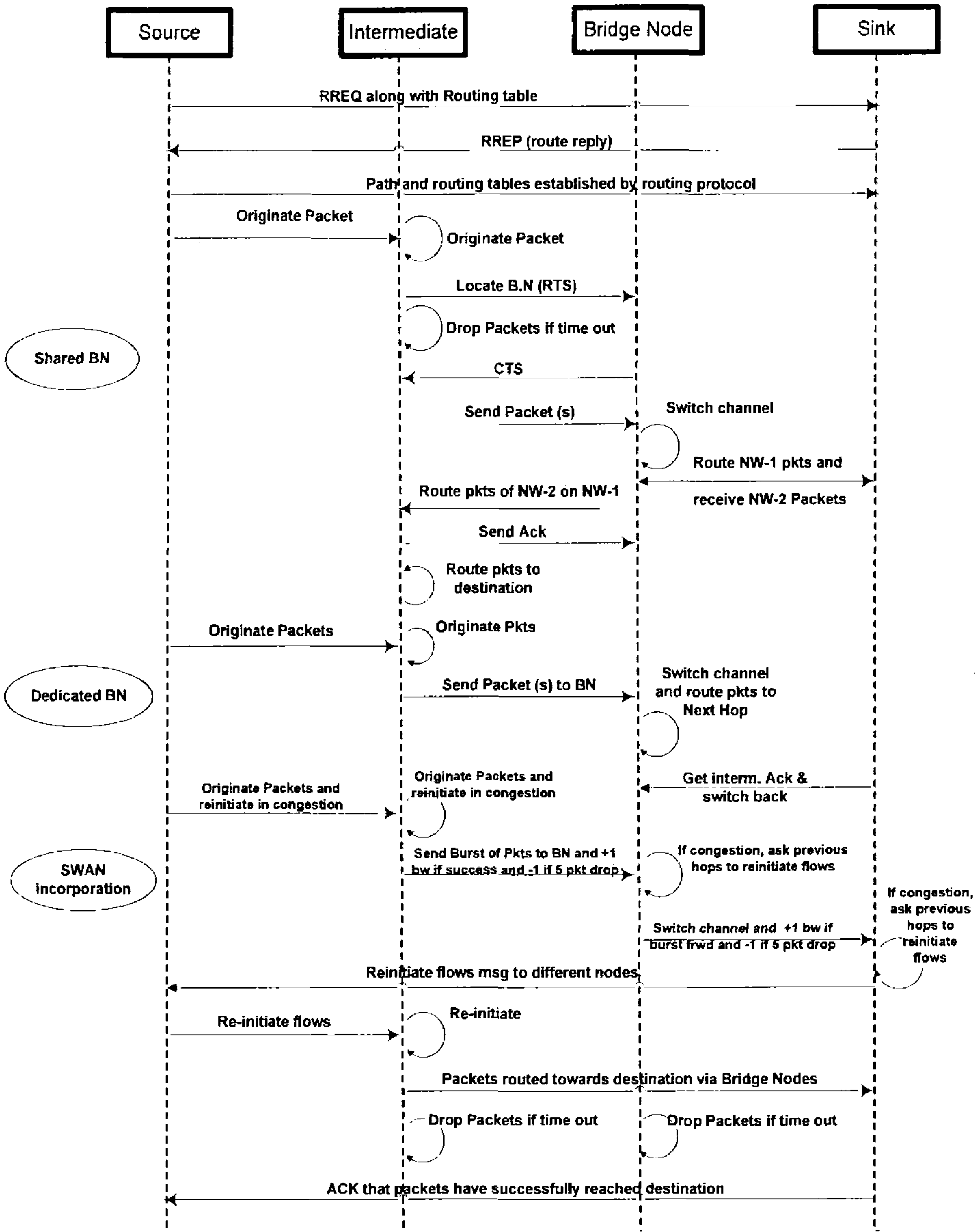

Figure 4.6: System Sequence Diagram

4.7 Summary

In this chapter we discuss our proposed solution in detail with the performance evaluation approaches which will clarify the feasibility of our proposed solution and results. In our proposed solution we develop two wireless mesh networks which are partially overlapped in their service area with the cost of bridge nodes, being registered on both the networks. Bridge nodes can be shared between networks or dedicated to their own network, for inter-communication. Their behavior can be of four types, as discussed. As there are few bridge nodes to pass both networks traffic so they got overloaded and packets will be dropped due to congestion.

To minimize the effect of congestion on overall system and packet drop, we incorporate SWAN QoS model, and mould it with respect to initially for WMN and later for overlapping networks. Our research work is to check practically and propose that this whether existing QoS solutions of adhoc are feasible for overlapped scenario as work for single networks. If yes, then at what cost; keeping in mind their original behavior does not change. So different set of parameters are streamlined on the basis of which, we intend to check its feasibility for handling the above mentioned issues in overlapping wireless mesh networks.

Chapter No 5

IMPLEMENTATION AND RESULTS

5.1 Simulation Scenario:

The purpose of the implementation phase is to put into operation the proposed system and check whether it show the desired results and achieves the objectives we wanted. We perform simulations in OMNET++ [47] which is an object-oriented modular discrete event network simulator. Our system consists of two wireless mesh networks which are partially overlapped. Both networks have their own non overlapped channels. As there are multi channels so we used IEEE standard 802.11b [8] which support three channels which are completely non-overlapped. We used single antenna which is Omni directional and has no intelligence, therefore all intelligence is found at MAC layer. Both wireless mesh networks are connected to internet through gateways which are WMN servers and act as sink. The nodes occurring in the overlapped area are marked as bridge nodes for inter network communication among two networks. Bridge nodes can pass traffic of both networks in both directions. In start of simulation routing protocol discovered and established routing paths. The topology of the network is formed and both networks set themselves on separate channels. The nodes identify themselves as sources, sink and bridge nodes. Then communication between nodes is started using MAC layer CSMA/CA mechanism.

5.2 Simulation Parameters:

There are different parameters which we use in our simulation environment.

Table 5.1: List of Simulation Parameters

Parameters	Value
Physical Layer Standard	802.11b
Source nodes	8
Sink nodes	2
Bridge nodes	4
World size	500*500
Simulation time	100 sec
Routing Protocol	OSPF
Traffic type	Video, FTP
Packet size	1KB-4KB
Channel switching time	80 micro-sec

There are different parameters which we use in our simulation environment, as listed in table-5.1. For wireless technology we have used 802.11b whose data rate is 11Mbps and have 3 orthogonal (non-overlapping) channels. In our simulation scenario source nodes are 8 and at last we enhance the topology to 12 source nodes. There are four bridge nodes and two gate ways acting as sink. The simulation time is taken as 100 seconds and routing protocol for underlying routing is OSPF. We use two traffic types i.e. FTP and video with 1KB and 4KB size. The switching time of bridge nodes between two networks is 80 micro-seconds.

5.3 Channel Hopping Effect

In single channel communication no channel hopping involve so packets are transmitted in less time as compared to multi channel communication because there is only communication delay. When we use multi channel some nodes have to switch channels to make the coordination possible among different networks operating on different channels and this will take some time. So multi channel communication involves switching delay along with normal delay of any communication shown in figure 5.1.

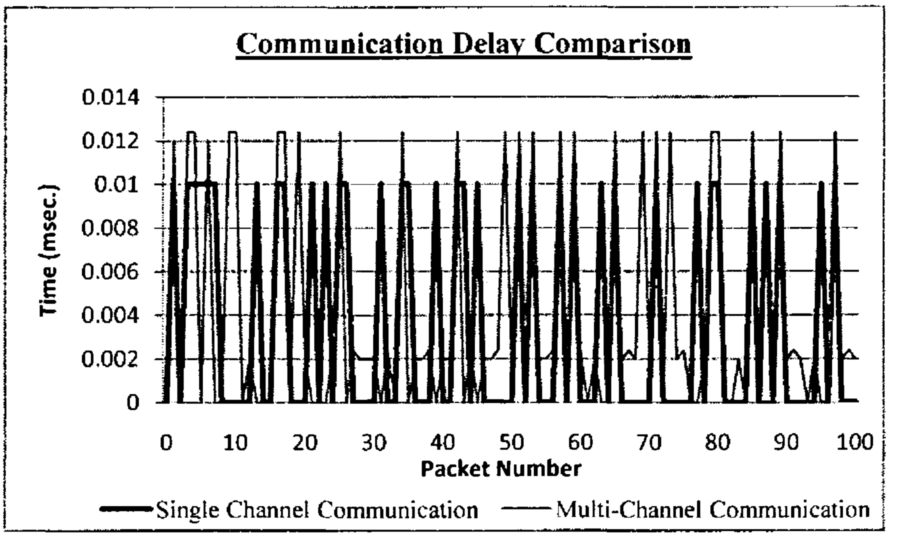

Fig. 5.1: Comparison of Single and Multi-channel Communication Delay

The transmission of packets from source to destination involves two steps or can be break down into two phase i.e. transmission of packets from sources to bridge nodes and then from bridge nodes to destination. Sources originate packets and directly send to bridge nodes with no channel hopping. Bridge nodes when receive packet(s), switch channel, locate next hop and forward packets in direction of destined gateway. It means forwarding of packets from bridge nodes involves switching delay along with normal communication and takes more time shown in figure 5.2.

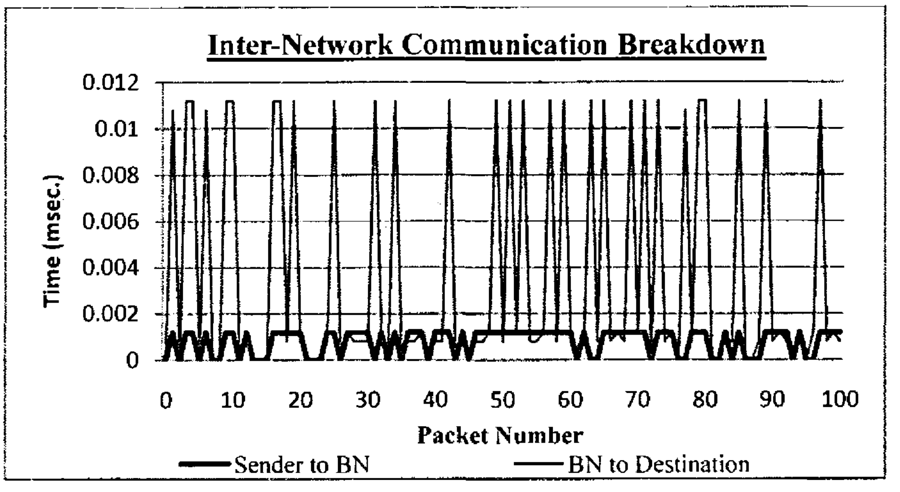

Fig. 5.2: Inter-Network Communication of Data by Bridge Nodes

5.4 Uniform Overlapped Networks

Our system consists of two overlapped networks with their own non overlapped channels and bridge nodes switch to both networks channels simultaneously. Bridge nodes act as a connecting link between two networks. Both networks are homogeneous in terms of no of nodes, data rate, traffic load and no of bridge nodes.

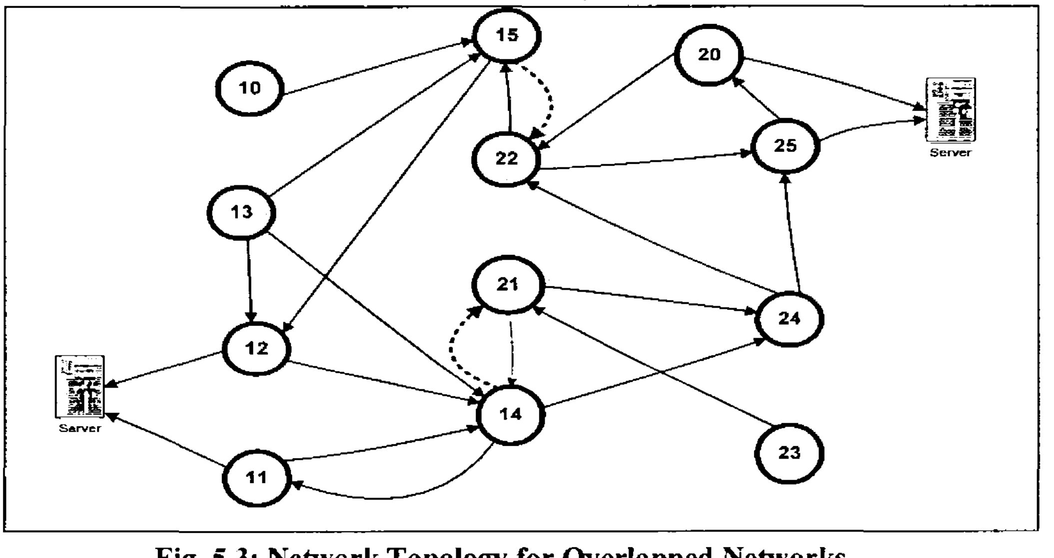

Fig. 5.3: Network Topology for Overlapped Networks

The bridge nodes are dedicated to their networks and entertaining their own network traffic directly and other network traffic indirectly by means of second network bridge nodes. The bridge nodes receive packet(s) from their network switch to other channel, forward packet (s) to next hops and again switch back to their respective channel.

Bridge nodes can communicate with other network nodes as well as second network bridge nodes because they work on both channels. To check the behavior and role of bridge nodes, we perform our simulation in two different scenarios which are discussed in the following. The origination of packets per second by sources is 10 packets.

5.4.1 Case-1: Networks Running Similar Applications (FTP-FTP)

In this case both networks have same type of traffic i.e. FTP. Source nodes on both sides of the networks are originating FTP flows whose packet size here is 1KB. The load on both sides of bridge nodes is equal in terms of no of packets and size of packets. Figure 5.4 shows the throughput of bridge nodes belonging to both networks in terms of no of packets entertained by bridge nodes. Approximately 400 packets are originated in every 5 sec. Since same types of application, so effect of bridge nodes of both networks is almost same. The total sent and drop packets are also shown in figure 5.4.

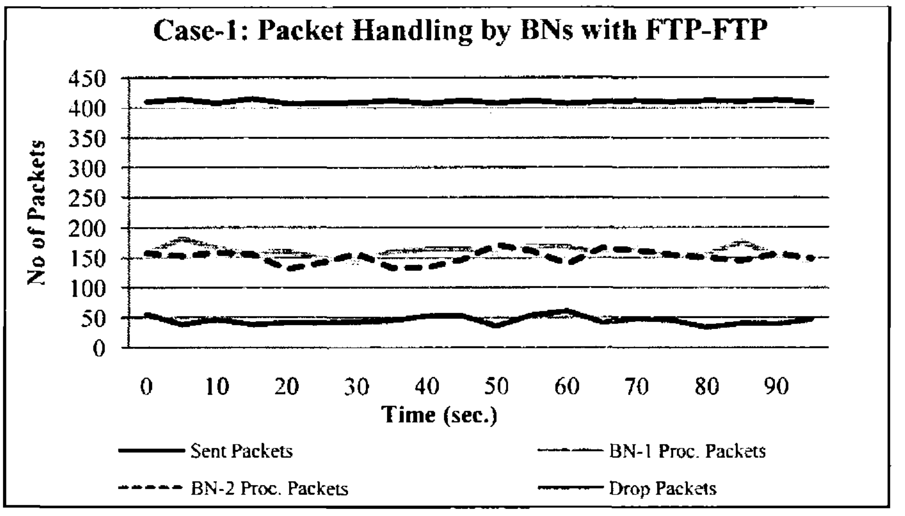

Fig. 5.4: Dedicated Bridge Nodes Handling Similar Traffic Flows

In figure 5.5 the effect of channel hopping by bridge nodes on packet drop is shown. The packets are dropped due to switching of bridge nodes on multi channels. Since bridge nodes are dedicated, nodes in one network can only send packets to their respective bridge node not the others. So when bridge nodes are on other network to forward packets, mean while all packets originating by nodes in its own networks are dropped if nodes don't find any bridge node.

The figure 5.5 shows the total originated packets by source nodes and no of reported packets (bridge nodes entertained packets+ drop packets by network). The difference between both lines is the no of packets dropped due to channel hop by bridge nodes which is approximately 53 packets on average in every 5 sec in this case.

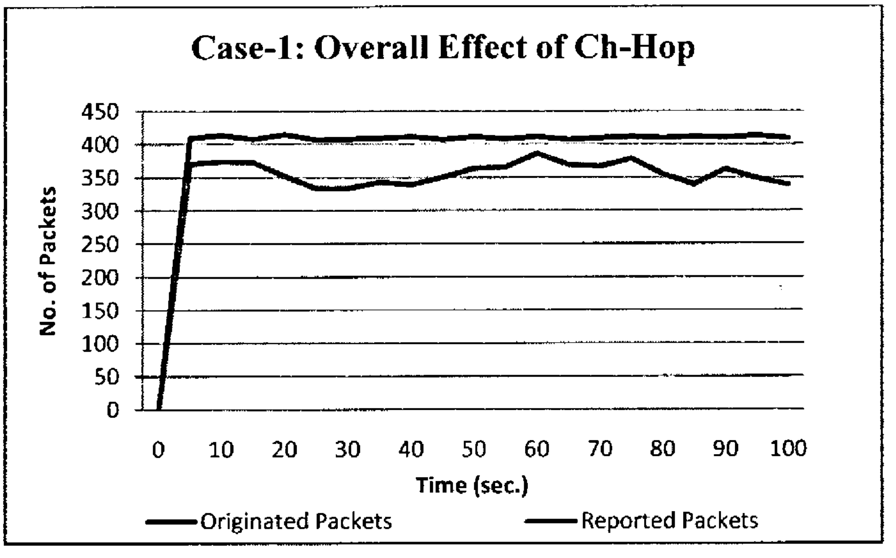

Fig. 5.5: Effect of Channel Hop on Packet Delivery with Same Size

5.4.2 Case-2: Networks Running Varying Applications (FTP-Video)

In this case both networks are originating and running different types of applications. The network-1 is originating Video flows of size 4KB where network-2 is originating FTP flows whose packet size is 1KB. So type of traffic on both sides is different and bridge nodes also handle different types of flows because size of packets and no of packets are different.

So behavior of bridge nodes is different shown in figure 5.6 which shows the no of packets processed by means of bridge nodes. The behavior of bridge nodes is different here. Total sent and drop packets by network are also shown in figure 5.6.

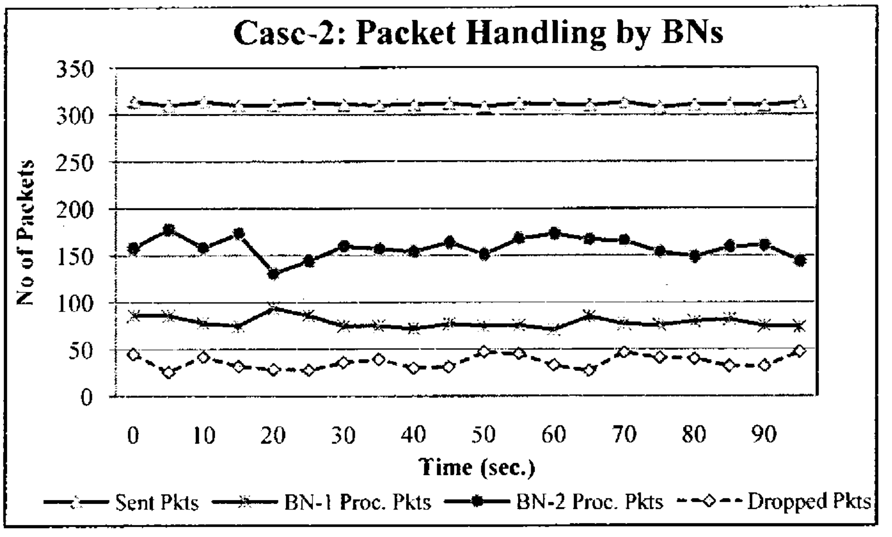

Fig. 5.6: Dedicated Bridge Nodes Handling Different Types of Traffic Flows

In figure 5.7 the effect of channel hopping by bridge nodes, on packet drop is shown. The figure shows the total originated packets by source nodes and no of reported packets (bridge nodes entertained packets+ drop packets by network), when networks running different applications. The difference between the total no of originated packets and reported packets is the no of packets dropped due to channel hop.

We can't directly keep track of packets dropped due to channel hop. From the below figure we can estimate easily that approximately 38 packets on average in every 5 sec. are dropped due to channel hop in this case. Packets dropped due to channel hop will be re-transmitted.

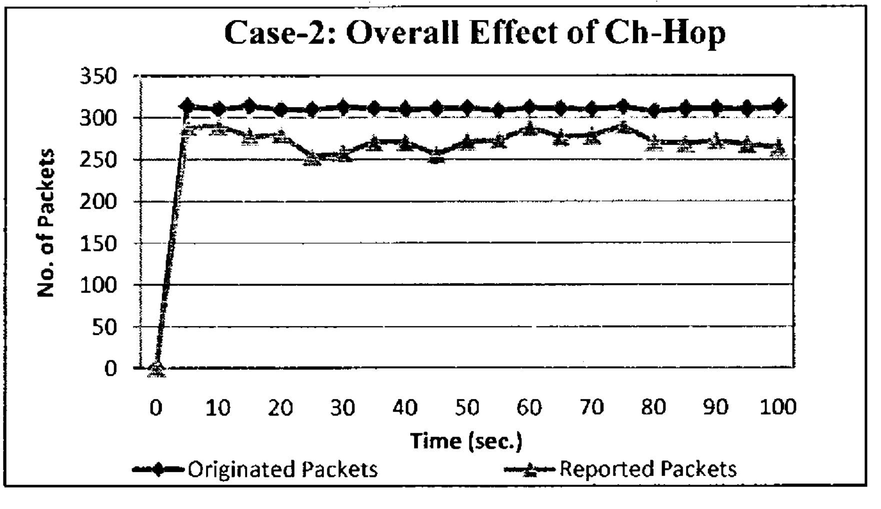

Fig. 5.7: Effect of Channel Hop on Packet Delivery with different Size

5.5 Congestion Handling with Modified SWAN

Channel hopping of bridge nodes results in packet drop which are re-transmitted. So along with normal packets, there will be re-transmitted packets. Also there are few bridge nodes to handle both networks traffic. So there will be congestion on bridge nodes even in normal scenario with fewer loads. To show the effect of congestion and to minimize packet drop due to congestion, SWAN Model is implemented and is tailored according to multiple overlapped wireless mesh networks with multi channels. Results show that SWAN handle congestion and work more efficiently than normal scenario especially in greater load and more traffic.

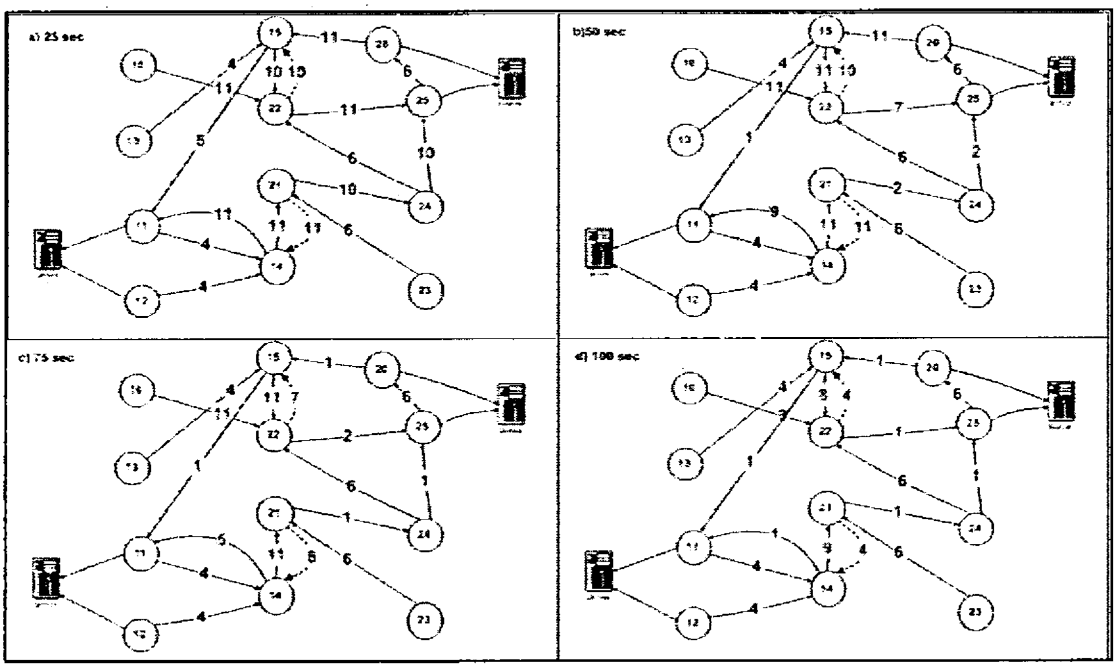

Fig. 5.8 (a): Dynamic Bandwidth Allocation by AIMD algorithm of SWAN (1K-1K)

There is normally no proper definition of congestion, taken as overload on network more than network can support and normally queues or load is used to define congestion which varies from scenario to scenario and show congestion. We used load to show congestion in system. In modified SWAN each node monitors traffic and ask previous node to reinitiate flows in case of congestion instead of original sources. There is extra overhead of channel hopping, if original sender is asked for flow-reinitiate, so, flow is adjusted between the both current nodes communicating the said flow [56].

We consider and keep track of data packets and bridge node channel hop for data packets, channel hopping for control packets as well, which is a future enhancement & out of scope of this study [28]. Rather than re-initiate the whole flow where MAC can treat it as re-transmission, focus is to adjust the next flow among the both nodes [57].

We used the AIMD algorithm of SWAN for dynamic allocation of bandwidth to flows especially real time flows. In start of communication nodes increase their data rate and bandwidth of the links is increasing accordingly shown in figures 5.8a and 5.8b, former with similar applications and latter with different applications on both sides of bridge nodes.

Since data rate is directly proportional to increased packet drop rate, so packet drop started which decrease the bandwidth. In this way data rate and bandwidth is increasing and decreasing and SWAN adjusting itself and finally its operation become smooth with less packet drop. In more loads it quickly adjusts itself. The min threshold is 1Mbps and max threshold is 11Mbps since we are using 802.11b. No Reroute options are considered: (i) Even if data rate between 2 nodes is minimum, constantly. (ii) Consecutive packets are dropped due to channel hopping of BN.

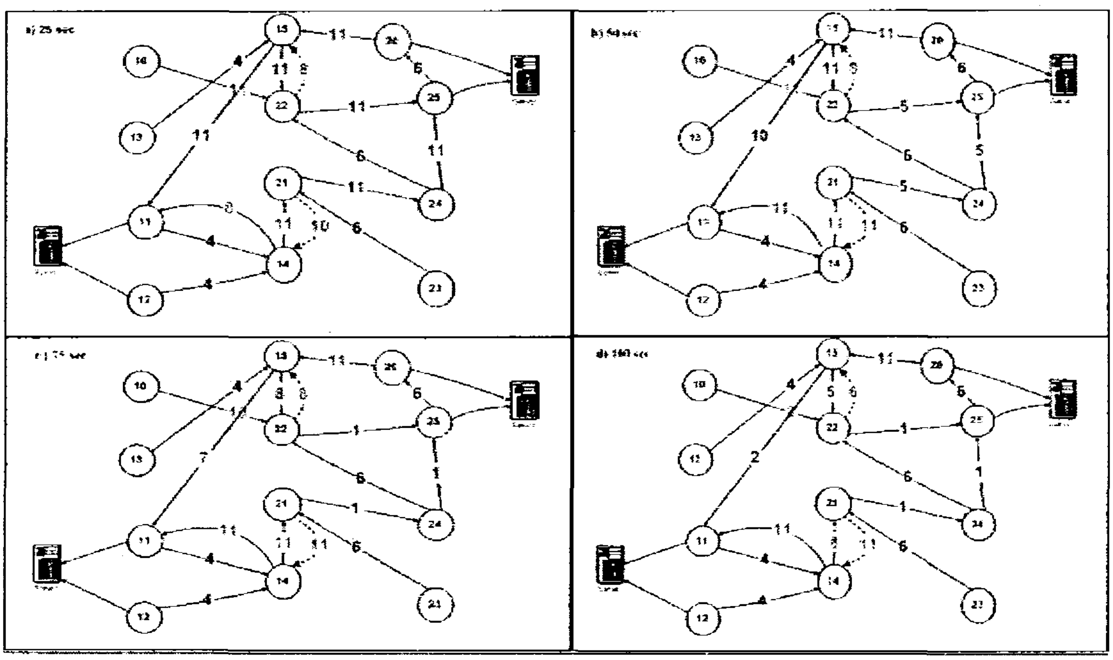

Fig. 5.8 (b): Dynamic Bandwidth Allocation by AIMD algorithm of SWAN (1K-4K)

5.5.1 Case-1: Networks Running Similar Applications (FTP-FTP)

In this case both networks have same type of traffic i.e. FTP. whose packet size here is 1KB. The load on both sides of bridge nodes is equal in terms of no of packets and size of packets. Figure 5.9 shows the overall system throughput with SWAN at 10pps. We can see that in half of simulation time SWAN is adjusting itself by AIMD and after 60 sec it operation become smooth and it handles the congestion then and decrease ratio of packet drop.

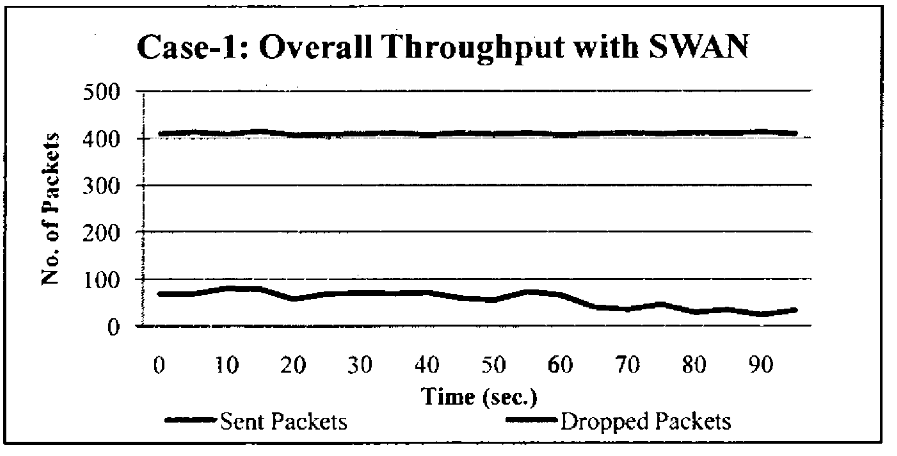

Fig. 5.9: Average Throughput with SWAN Operating on Similar Appiications

5.5.2 Case-2: Networks Running Varying Applications (FTP-Video)

In this case both networks are originating and running different types of applications. The network-1 is running FTP flows of size 1KB where network-2 is originating video flows whose packet size is 4KB at the rate of 10 pps.

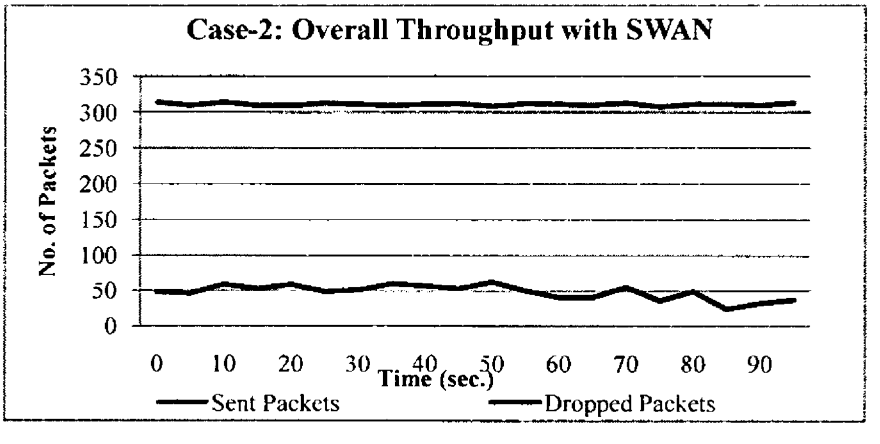

Fig. 5.10: Average Throughput with SWAN Operating on Different Applications

Figure 5.10 shows the behavior of SWAN when networks are operating at different applications. We can see that after adjusting itself, there is decrease in packet drop. Since load is less so in most of the simulation time SWAN adjust itself. When SWAN adjusts itself by AIMD algorithm, then there is turn down in the graph.

5.6 Evaluation with Increased Traffic

In this section an analysis of different scenarios in terms of varying load and traffic types is discussed. As discussed earlier, the focus is still on highlighting the entities acting as bottleneck within the system.

5.6.1 Behavior of Bridge Nodes

In this section the behavior of bridge nodes with different packet sizes and load is analyzed. Figure 5.11a shows the status of bridge nodes when traffic type on both sides of bridge nodes is same i.e. FTP flows. Since traffic type is same so load by both networks on their dedicated bridge nodes is almost alike. The variation may be in terms of random traffic generation parameters and channel hopping effect.

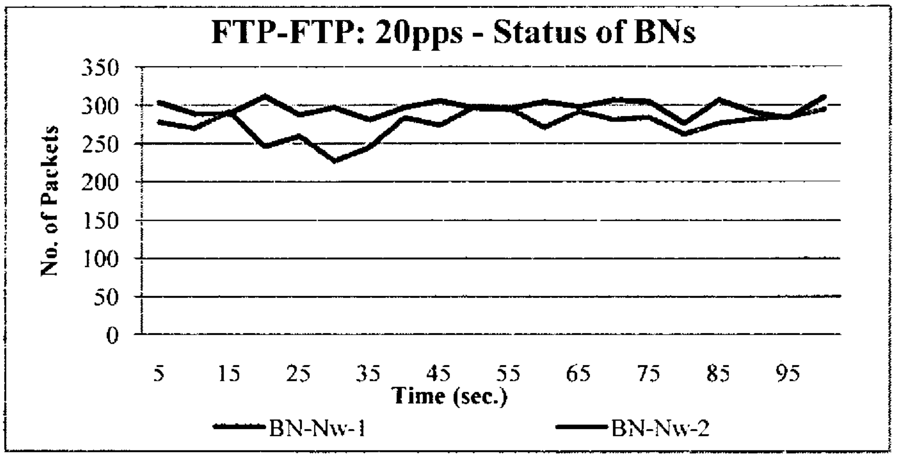

Fig. 5.11a: Status of Bridge Nodes Handling Similar Traffic Types

In figure 5.11b traffic types of networks are different. So status of bridge nodes is different. Bridge nodes of network1 handles approximately 300 packets where bridge nodes of network2 entertained approximately 100 packets in every 5 second. It means network1 bridge nodes handle packets whose size is less i.e. FTP flows. Where no of packets handles by network-2 bridge nodes is less since they handle video flows whose size is larger.

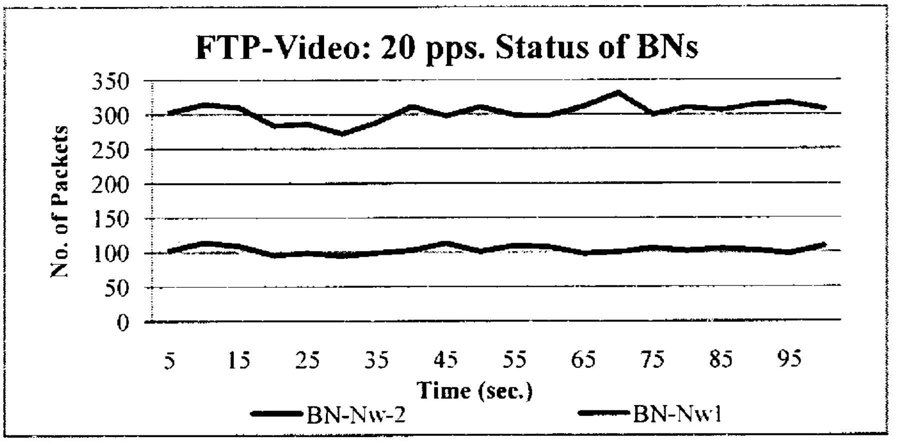

Fig. 5.11b: Status of Bridge Nodes Handling Different Traffic Types

Figure 5.12 shows a comparison of packets dropped by bridge nodes during congestion in both networks, both for FTP-FTP and for FTP-Video. In first case both networks originate almost equal no of packets due to same packet size i.e. approximately 7700 packets by each network, where in FTP-video network-1 originate approximately 7600 packets and network-2 originate approximately 3000 packets. Bridge nodes drop packets are different in ratio. Bridge nodes receive more packets, drop more packets, as they have to channel hop for each and every packet.

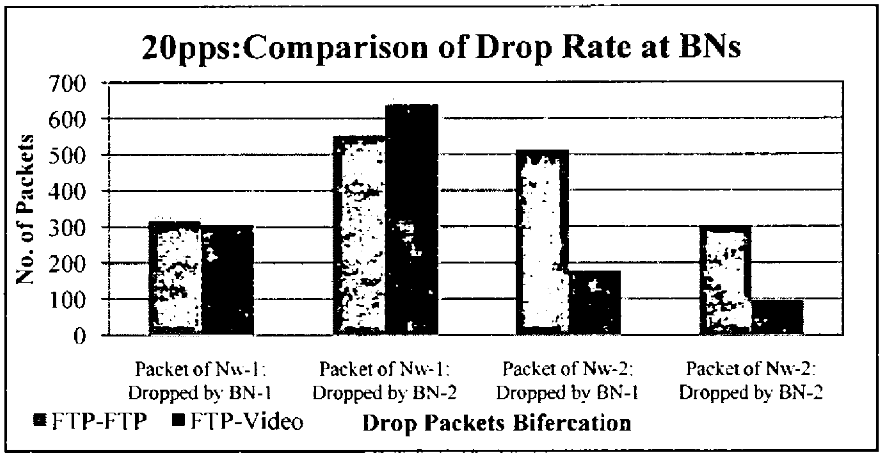

Fig. 5.12: Comparison of Packet Dropped at Bridge Nodes

5.6.2 Channel Hopping

In this section an analysis and comparison of packet drop due to channel hop with different traffic types and different traffic load is given. Since packets are dropped due to bridge nodes channels hopping, so its effect on packet delivery ratio is shown.

Figure 5.13 shows the no of packets entertained by bridge nodes, dropped due to channel hop and reported as dropped due to congestion or any other reason. Results of both scenarios are shown when nodes originate packets at the rate of 20pps and figure 5.14 shows the same thing but with more load i.e. 30 pps.

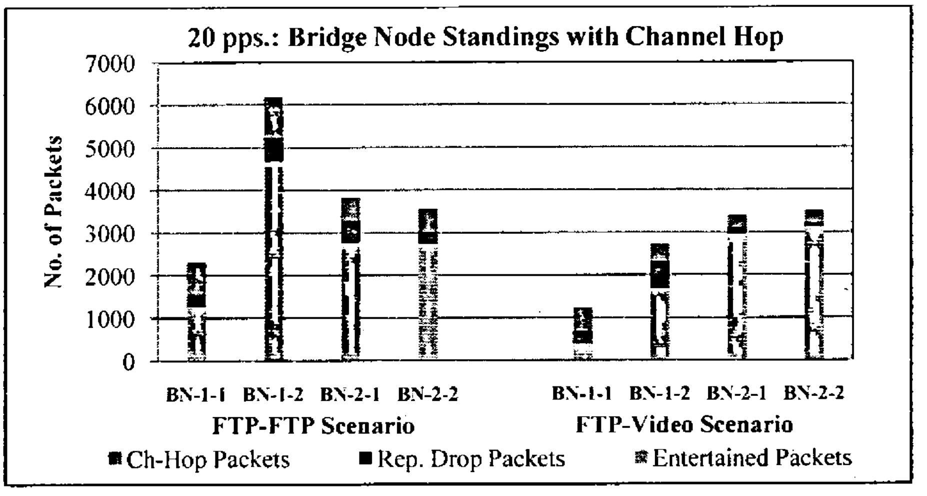

Fig. 5.13: Comparison of Reported Drop and Channel Hop Drop Packets at 20pps

We can see that some packets are dropped due to channel hop by bridge nodes. Bridge nodes are network dedicated and they switch channel only for sake of their own network traffic forwarding. The packets are drop when nodes don't find any bridge node to forward their packets as bridge nodes are on other channel at that time. So channel hopping has it cost which is shown. In FTP-Video scenario less no of packets are originated because size of video packets is large.

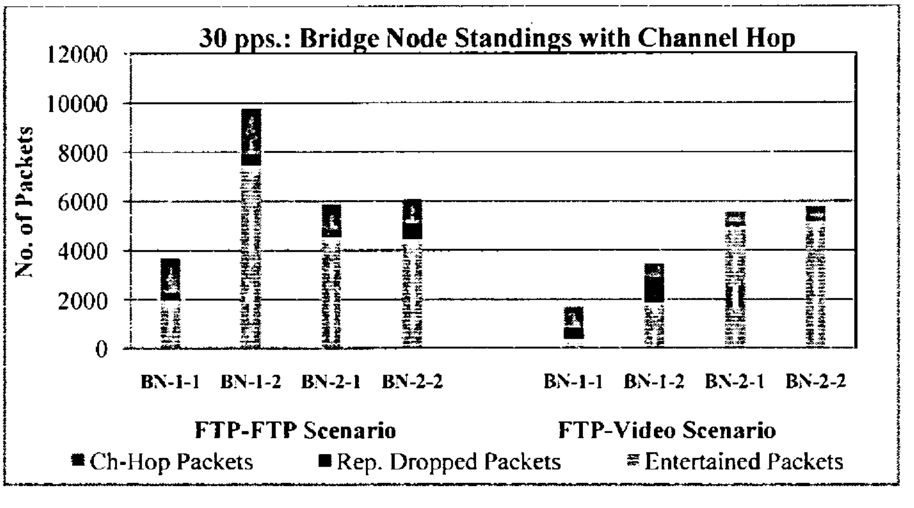

Fig. 5.14: Comparison of Reported Drop and Channel Hop Drop Packets at 30pps

5.6.3 SWAN with Varying Traffic Load

In this section the behavior of tailored SWAN for handling congestion and minimizing packet loss is analyzed and compared with normal scenario. Results shows the SWAN outer perform the normal scenario and show its efficiency for minimizing packet drop. In normal scenario without SWAN packets are dropped at a constant rate and can be compared with SWAN where in start more packets are dropped but once SWAN adjust itself, there is decrease in packet drop shown in figure 5.15 and 5.16 easily. In FTP-FTP with 20 pps, the packet drop in normal scenario is 11.5% where with SWAN the packet drop is 9%. In figure 5.15 we can see that in first 25-30 sec SWAN adjust itself and then start working.

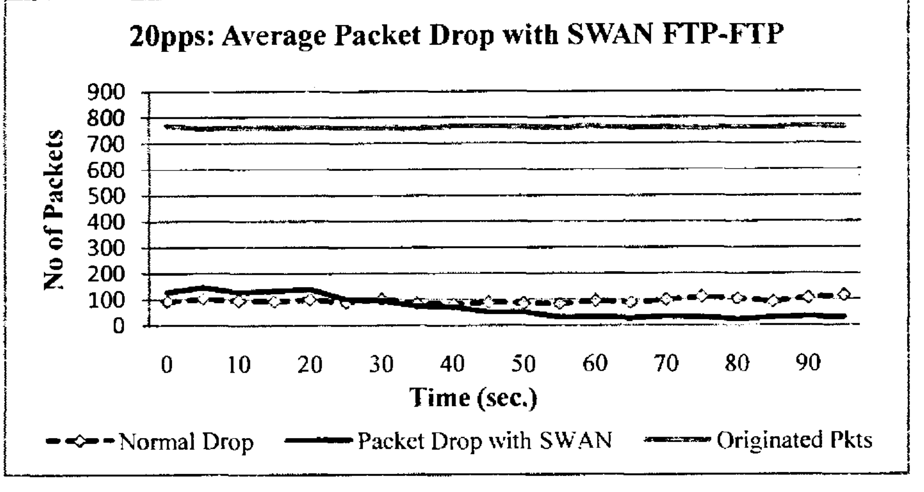

Fig. 5.15: Minimizing Packet Drop by SWAN with Equal Packet Size

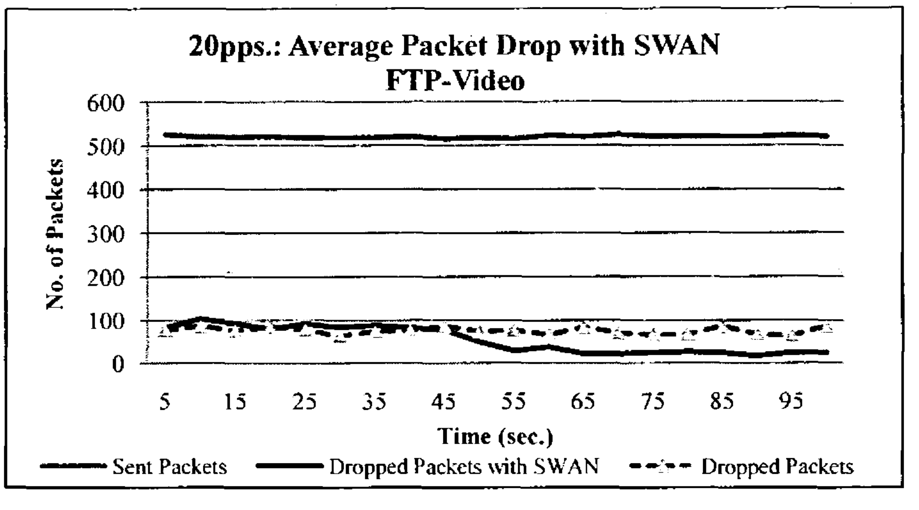

Fig. 5.16: Minimizing Packet Drop by SWAN with Different Packet Size

Figure 5.16 show the scenario, when SWAN operating with networks running different applications. Load in terms of no of packets and size of packets is different in figure 5.16 but there is a clear turn down in packet drop by SWAN. Figure 5.17 and 5.18 shows and compare the packet drop with SWAN and without SWAN, when packets are originated at the rate of 30 packets per second. In figure 5.17 the total no of sent packets is approximately equal to 25500 in both with FTP-FTP but packet drop in normal scenario is 11% and packet drop with SWAN is 6.8% which is clearly shown in figure 5.17.

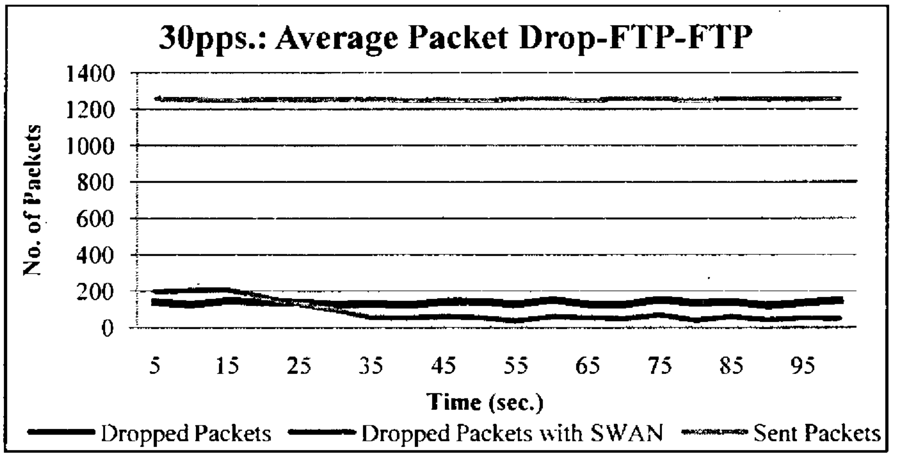

Fig 5.17: Comparison of Congestion Handling by SWAN (FTP-FTP)

Figure 5.18 shows the scenario when both networks work on different types of traffic. The total originated packets are approximately equal to 16000 in both cases. The packet drop with no SWAN is equal to 11.5% and packet drop with SWAN is 8%.

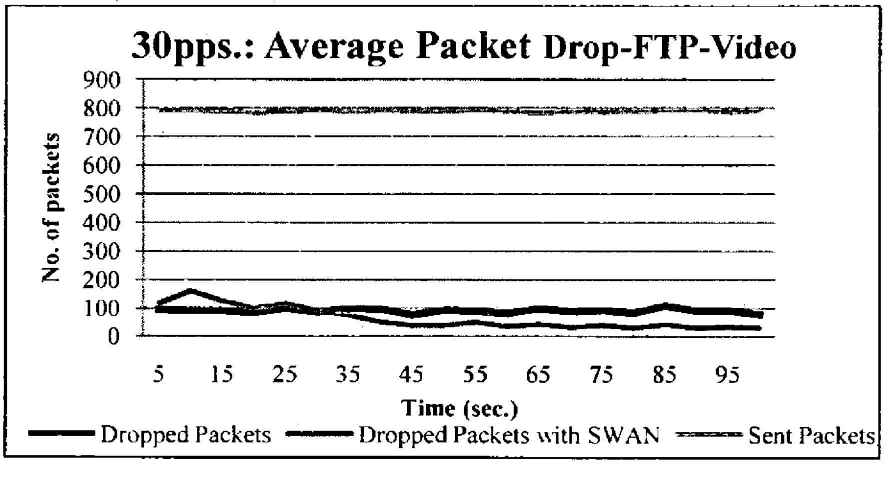

Fig. 5.18: Comparison of Congestion Handling by SWAN with Normal Scenario

5.7 Overlapped Networks with Shared Bridge Nodes

In this section we study and analyzed overlapped networks with shared bridge nodes. Both overlapping domains are completely shared and coordinated and bridge nodes receive and forward packets not only from their own network as well as from other network. We check the behavior of shared BNs with both FTP and Video flows when nodes originate packets at 20 pps (packets per second). Figure 5.19 show the network wise packet handling of bridge nodes, that number of packets entertained by network1 BNs and packets entertained by network2 BNs.

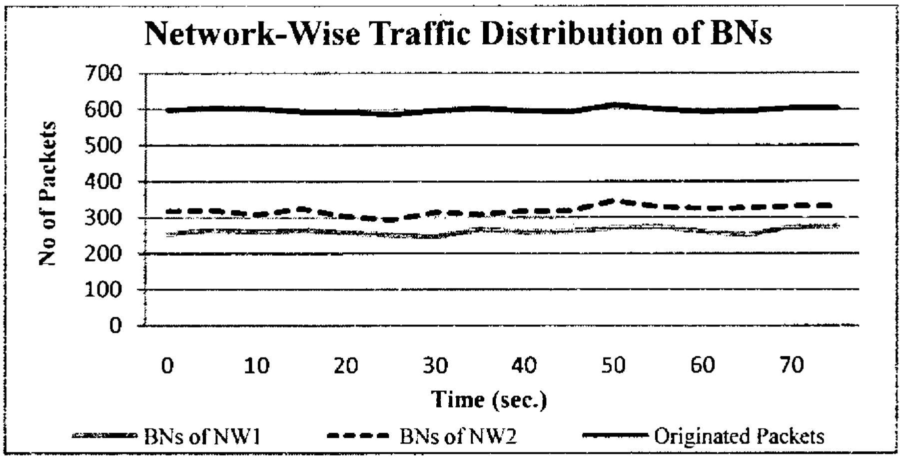

Fig.5.19: Shared Bridge Nodes Network-wise Division of Traffic

In figure 5.20 type of traffic on both sides of BNs is different i.e. FTP-Video at 20 pps. Figure 5.20 shows the bridge nodes packet handling belongs to their own network and to other network.

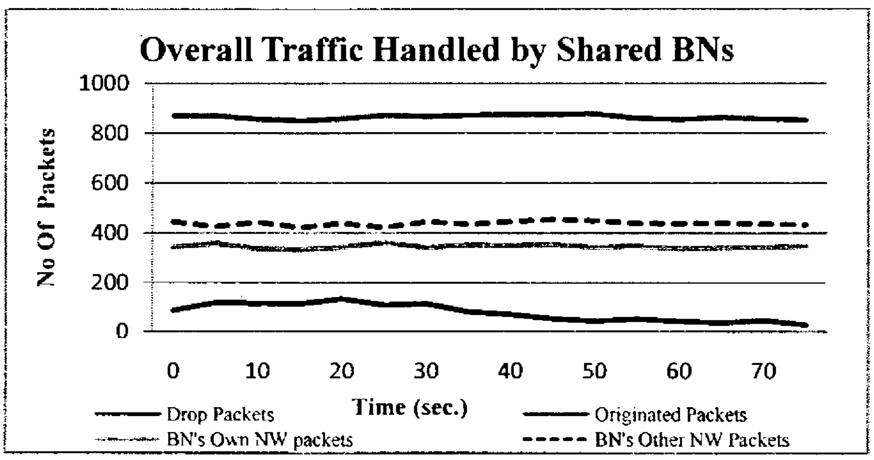

Fig.5.20. Status of Shared Bridge Nodes with Similar Applications

Since bridge nodes are shared in figure 5.20 so they handle approximately 400-420 packets of other network and approximately 380 packets on average of own network.

5.8 Analysis and Comparison

In this section an analysis of SWAN with both shared and dedicated BNs with increased network size i.e. 16 nodes shown in figure 5.21, is given earlier and later a comparison of SWAN with normal scenario in terms of packet drop is discussed and also performance comparison of shared and dedicated BNs is given to find and optimal and feasible solution. The no of sources are increased to 12 from 8 in both networks. The no of bridge nodes is same. The solution is analyzed with different traffic types and with different load.

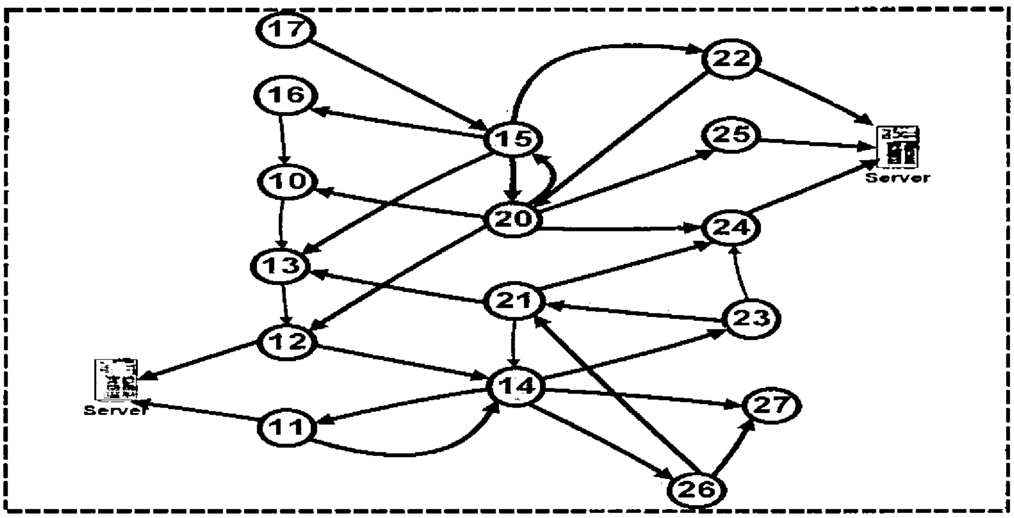

Fig. 5.21: Network Topology with 16 Nodes

5.8.1 Increased Networks with Dedicated Bridge Nodes

In this section we analyze our solution with increased number of sources in both networks when BNs are dedicated. We test it for both cases i.e. FTP-FTP and FTP-Video. In FTP-FTP the load on both sides of bridge nodes is equal in terms of no of packets where in FTP-Video the load in-terms of number of packets is different but in terms of size (number of bits) is equal. Figure 5.22a shows the 16 nodes scenario with SWAN and BNs dedicated when networks originate similar application and analysis of packet drop due to channel hop and due to congestion with different load is shown. Channel hopping cost is clearly shown. SWAN handles the congestion and minimizes the packet drop due to congestion but packet drop due to channel hop can't be controlled since no queues are used and worst case scenario being analyzed.

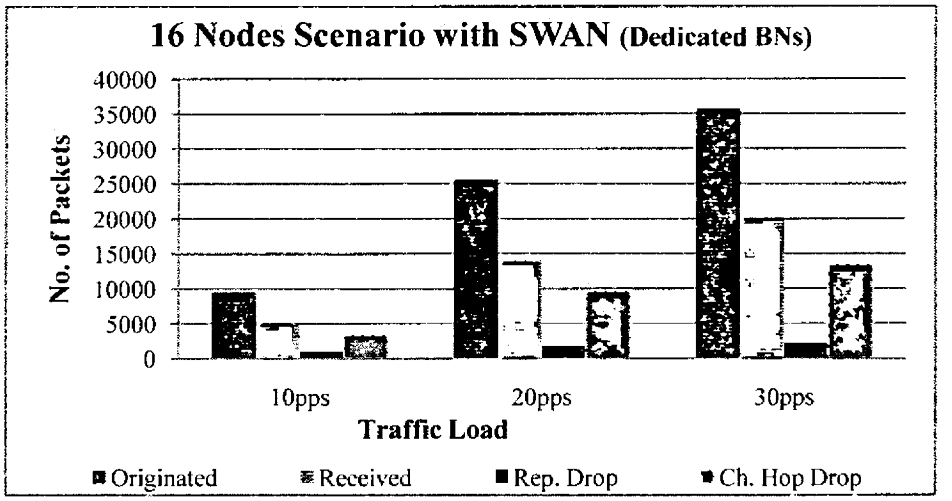

Fig. 5.22a: Analysis of Reported Drop and Channel Hop Drop (FTP-FTP)

Figure 5.22b shows the 16 nodes scenario with SWAN when networks originate different applications and analysis of packet drop due to channel hop and due to congestion with different load is shown. In this case since traffic types are different, number of packet origination on one side is less than the other but packets are different in terms of number not in terms of size (bit per sec). SWAN minimizes normal packet drop but channel hop drop increases as load increases as shown in figure 5.22a and 5.22b because BNs channel hop for each packet.

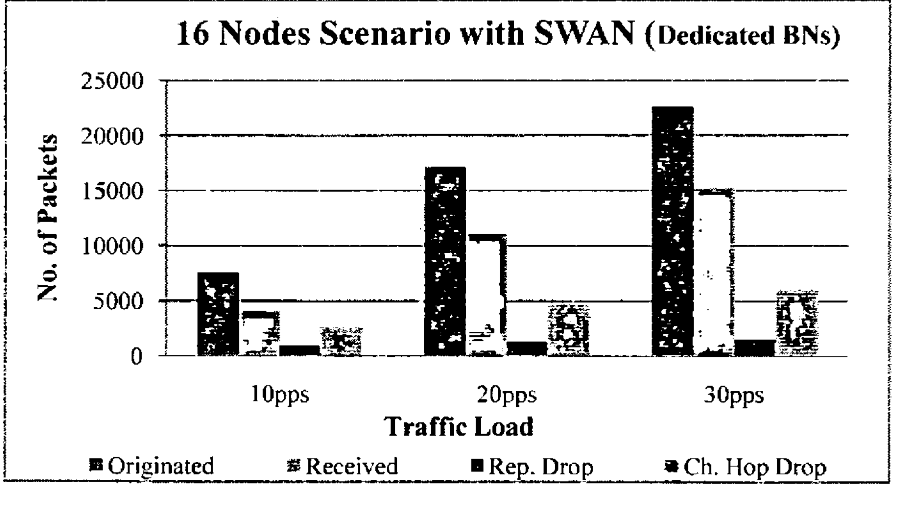

Fig. 5.22b: Analysis of Reported Drop and Channel Hop Drop (FTP-Video)

5.8.2 Increased Networks with Shared Bridge Nodes

In this section we analyze our solution with increased number of sources in both networks when BNs are shared. We test it for both cases i.e. FTP-FTP and FTP-Video. In FTP-FTP the load on both sides of bridge nodes is equal in terms of no of packets where in FTP-Video the load in-terms of number of packets is different but in terms of size (number of bits) is equal. Figure 5.23a shows the 16 nodes scenario with SWAN and BNs being shared when networks originate similar application and 5.23b shows the scenario when networks originate different applications.

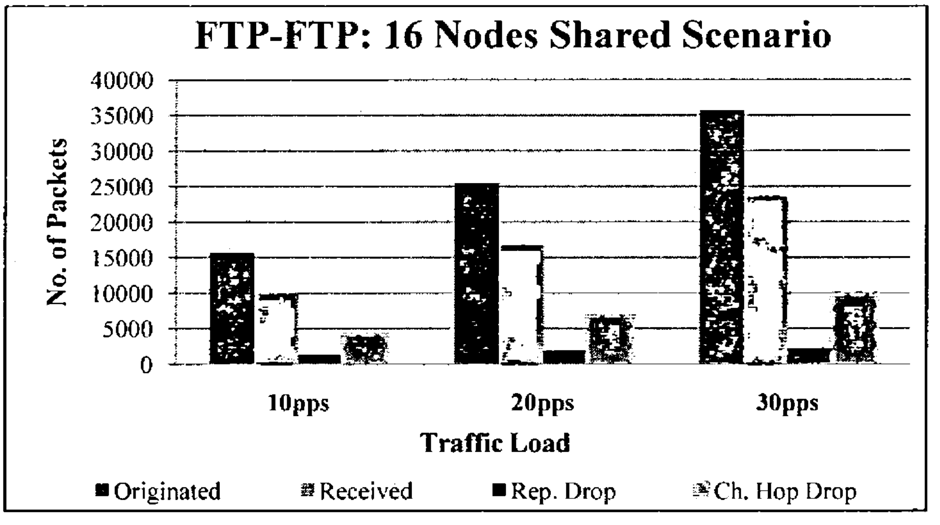

Fig. 5.23a: Analysis of SWAN with Shared BNs-16 Node Scenario (FTP-FTP)

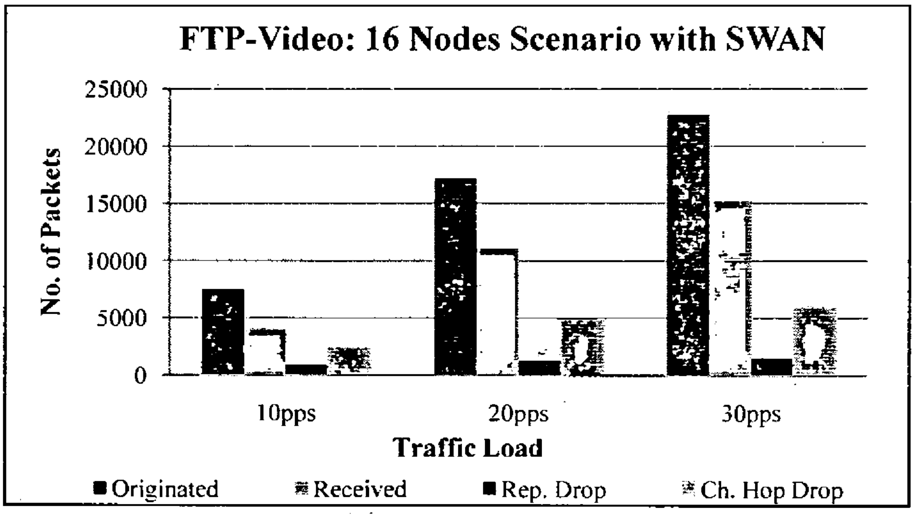

Fig. 5.23b: Analysis of SWAN with Shared BNs (FTP-Video)

Since BNs are shared so we can see that number of originated and received packet are more as compared to dedicated shown in figure5.22a and 5.22b because nodes find BNs more than dedicated so cost of channel hopping is less as compared to dedicated BNs. Less packets are dropped due to channel hop which ultimately increased number of received packets shown in figure 5.23a and 5.23b.

5.8.3 Comparison and Discussion

In this section we analyze and compare our simulation results in form of tables to show the feasibility of our proposed solution and show an optimal and feasible solution. We compare our solution with normal scenario and results show that our solution controls the congestion and packet drop without technique is less as compared to normal scenario.

Table 5.2 show comparison of our tailored SWAN with normal scenario at different traffic loads and different traffic types to show its feasibility.

Table 5.2: Comparison of Packet Drop of SWAN with Normal Scenario

	Packets Per sec	**No SWAN**	**SWAN with 12-Nodes**	**SWAN with 16-Nodes**
1K-1K	10	12%	13.8%	11%
	20	11%	9%	7%
	30	11%	6.8%	6%
1K-4K	10	11.7%	14%	12%
	20	11.5%	10%	7.5%
	30	11.6%	8%	6.5%

In table 5.2 we can see that when load is less, then in most of the simulation time SWAN is found struggling to adjust itself and there is more packet drops. This is because it needs some time to become stable which is evident in case of increased network size and increased load, where SWAN quickly adjusts and there is less packet drop. So we can see and conclude that SWAN work better in more loads and handle congestion efficiently and minimize packet drop considerably as compared to normal scenario.

Table 5.3: Comparison of Shared and Dedicated BNs for Packet Drop

	Packets Per sec	Shared BNs	Dedicated BNs
1K-1K	10	12.4%	13.8%
	20	8.9%	9%
	30	6.7%	6.8%
1K-4K	10	13%	14%
	20	9%	10%
	30	7.2%	8.1%

In table 5.3 we compare shared BNs with Dedicated BNs in terms of packet drop. The no of packet drop in case of congestion at dedicated is slightly more than shared because in dedicated all load is on two bridge nodes where in shared this load is divided among four bridge nodes. So the throughput of networks/system with shared is high as more packets are entertained by bridge nodes.

Table 5.4: Comparison of Shared and Dedicated BNs for Channel Hop Cost

	Packets Per sec	Shared BNs	Dedicated BNs
1K-1K	10	10.11	27
	20	9.4	25.4
	30	8.5	26.5
1K-4K	10	5.5	26
	20	2.8	21.7
	30	1.3	20.4

In table 5.4 we compared the shared BNs with dedicated BNs for channel hopping cost. We calculate the channel hopping cost as number of packets dropped w.r.t sent packets. The cost of channel hopping for shared bridge nodes is less than dedicated bridge nodes. The cost of channel hopping in shared BNs becomes half in FTP-Video because in case of FTP-video less number of packets are originated as size of video packets is larger so result is less channel hop. The cost of channel hopping for shared bridge nodes is less than dedicated bridge nodes and it also decreases with increased load because nodes switch to new channel for forwarding their packets and taken other network packets when returned back to their own network instead of being switching back free as in dedicated bridge nodes.

So we can say that our solution works better than normal scenario and if bridge nodes are shared between networks, the performance of system is better means inter domain coordination is necessary to increase performance. Packet drop due to channel hop is apparently seems the limitation of our solution but actually it is not limitation as we analyzed worst case scenario i.e. BNs channel hop for each packet. This can be eliminated by minimizing channel switching time and by using queues. So that BNs will channel hop for multiple packets instead of single packet which will ultimately increased number of received packets and also throughput is expected to increase, if multiple packets are transmitted after Ch-Hop by BNs.

5.9 Summary

In this chapter we discuss our simulation environment, parameters, simulation scenarios and results. The effect of multi-channels, channel hopping on system throughput and packets dropped due to channel hopping is discussed. Along with packet drop due to congestions, packets are also dropped due to channel hopping of bridge nodes, which shows the cost of channel hopping. We discuss two cases for bridge node behavior i.e. dedicated bridge nodes and shared bridge nodes, handling same type of application and different types of application with different traffic loads. When both networks originate same type of traffic behavior of bridge nodes is almost same since packet size is same. But when packet size is different then they behave differently.

Later SWAN QoS model is implemented to handle congestion and minimize packet drop and compare its results with normal scenario. Results show the feasibility of SWAN that it works better and there is less packet drop as compared to normal scenario. Later solution is checked with increased network size for both shared and dedicated BNs to verify the results. In both cases SWAN outer perform the normal scenario by handling congestion. At last comparison of results is to show feasibility of solution and also comparison of shared and dedicated BNs is presented and found that performance of system is better with shared bridge nodes.

Chapter No 6

CONCLUSION AND FUTURE WORK

When individual WMNs become overlap and if there is no coordination in Overlapping wireless mesh networks, their capacity, performance and throughput will be decreased due to interference among the neighboring nodes. So proper interworking of these overlapping WMNs by mean of bridge nodes is very necessary. Since there will be few bridge nodes which will handle traffic of both domains so there will be congestion on these bridge nodes which should be handled to minimize packet loss.

The focus of our research is to interlinked two overlapping wireless mesh networks, provide proper interworking between these networks by means of bridge nodes, check behavior of bridge nodes, show multi-channel communication delay, channel hopping effect on packet delivery ratio and investigate the feasibility of SWAN as an underlying model for provisioning of QoS in terms of congestion handling and minimizing packet drop in these overlapping WMNs. Two wireless mesh networks are developed which are partially overlapped in their service area and having nodes in this area termed as bridge nodes which provide coordination among them.

6.1 Conclusion

The communication delay of multichannel system is more than single channel because nodes have to switch between multi-channels and communication is completed in two steps rather than in a single flow. Along with packet drop due to congestions, packets are also dropped due to channel hopping of bridge nodes, which shows the cost of channel hopping. Because due to bridge node hopping, packets will be drop due to their absence on that network and there will be retransmissions.

We discuss two cases for bridge node behavior i.e. dedicated bridge nodes and shared bridge nodes, handling same type of application and different types of application with different traffic loads. When both networks originate same type of traffic behavior of bridge nodes is almost same since packet size is same. But when packet size is different then they behave differently. Bridge nodes handles FTP packets entertain more packets than bridge nodes handling video packets. Since there is congestion and packet drop in networks and bridge nodes which effect overall network performance in terms of packet loss, throughput etc. So we incorporate SWAN QoS model, and mould it with respect to initially for WMN and later for overlapping networks and compare its results with normal scenario where there is no QoS provisioning in terms of congestion handling.

Results show the feasibility of SWAN hat it works better and there is less packet drop as compared to normal scenario. We check it two scenarios, one for different traffic types i.e. FTP and video and FTP-FTP with both 12 nodes and 16 nodes. In both cases SWAN outer perform the normal scenario by handling congestion. The percentage of packet drop by SWAN is less than without SWAN. Results show that in start SWAN takes some time to adjust itself and then there is clear decline in packet drop. Results show that SWAN QoS model work well on overlapping networks and show same results with different network loads. SWAN work better in more loads and handle congestion efficiently and minimize packet drop considerably.

The channel hopping has its cost and packets are dropped due to channel hop by bridge nodes. Because bridge nodes switch channel for every packet and we used no queues. The cost of channel hopping for shared bridge nodes is less than dedicated bridge nodes and it also decreases with increased load because nodes switch to new channel for forwarding their packets and taken other network packets when returned back to their own network instead of being switching back free as in dedicated bridge nodes. We can't control the packet drop due to channel hop in our scenario. The scenario we taking is worst case scenario.

So we can say that our solution works better than normal scenario and if bridge nodes are shared between networks, the performance of system is better with shared BNs than dedicated means inter domain coordination is necessary to increase performance. Packet drop due to channel hop is apparently seems the limitation of our solution but actually it is not limitation as we analyzed worst case scenario i.e. BNs channel hop for each packet. This can be eliminated by minimizing channel switching time and by using queues. So that BNs will channel hop for multiple packets instead of single packet which will ultimately increased number of received packets and also throughput is expected to increase, if multiple packets are transmitted after Ch-Hop by BNs.

The main contribution of our work is summarized in the following:

- Provision of Multi-hop WMNs being overlapped. Overlapping Wireless Mesh Networks are properly coordinated and interlinked via bridge nodes.
- Bridge Nodes Characteristics:
    - a) Coordinated Assignment/ Registration
    - b) 2 (out of 4) scenarios analyzed: Shared & Dedicated BN
- Check behaviour of bridge nodes with both networks originating same traffic with equal packet size and networks originating different traffic with different packet size and loads.
- Multi channels of both domains are handled properly and show communication delay of multi-channel due to channel hopping and effect of channel hopping on packet delivery.
- Check the feasibility of SWAN for handling and minimizing congestion and packet loss more efficiently than normal scenario with no QoS mechanism.
- Our work suggest that Adhoc protocols and QoS solution can work as well on overlapping WMNs and increase their performance by keeping their original behavior does not change.

6.2 Future Work:

We check our solution for throughput of overlapped networks and take two types of traffic i.e. FTP and video. Our solution can be extended as follow:

6.2.1 Flow Specific Bridge Nodes

The flows specific bridge nodes cases discussed in the proposed solution in which bridge nodes will be traffic specific and pass only one particular type of traffic and not allow other type of traffic flows to pass through it ,even these flows belong to its own network. May be theoretically it seems that these are not feasible but need to analyze for large networks where we want to give priority to a particular type of traffic.

6.2.2 More Types of Traffic

We used two types of traffic flows i.e. FTP and video. Our solution can be checked for other traffic types like web, HTTP, audio etc with different packet sizes. Broadly speaking in terms TCP and UDP traffic specifically can be tested.

6.2.3 For Other 802.11 Standards

Wireless networks are based on 802.11 technologies. We used 802.11b in our system. Our solution can be implemented at checked on other different IEEE 802.11 standards like 802.11a and 802.11g. This way, more data rate is acquired that may lead to fewer packet losses.

6.2.4 For Increased No of Networks

We use two overlapping networks. The work can be extends with more than two overlapping domains and with increase network size in terms of sources, sink and bridge nodes, running different applications/ different packet sizes.

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