Chapter 1
Introduction

1.1 General

Wireless mesh networks (WMNs) (Ian F.Akyildiz et.al.,2005),(Nandiraju DVS., 2010) is a newly evolving technology in wireless networks resembling MANET (P. Venkata Krishna et.al., 2012) in certain features. Mesh clients and mesh routers are the comprising nodes in WMNs. WMNs is a dynamic technology which can organize and configure itself as its nodes can create an ad hoc pattern network and establish and maintain internode mesh connectivity. Conventional nodes such as Desktops, PDAs, laptops, Pocket PCs, phones, etc., having wireless network interface cards (NICs) can establish a direct connectivity with the wireless mesh routers. It is possible even for those clients not having the wireless NICS to connect to the mesh routers through, for instance, Ethernet. Hence, WMNs can help the users to get connected from almost anywhere and at anytime. Besides, WMNs can be integrated with the existing wireless networks including cellular, wireless sensor, wireless-fidelity (Wi-Fi) (P.Venkata Krishna et.al.,2009), worldwide inter-operability for microwave access (WiMAX)(Misra.S et.al.,2013), WiMedia networks(P.Venkata Krishna,2008) through the gateway/bridge functionalities embedded in mesh routers. As a result, these networks can provide the users of the existing networks certain effective network services through integration with WMN. WMN is an upcoming novel wireless technology capable of addressing numerous network applications such as broadband home networking, community and neighborhood networks, enterprise networking, building automation etc. Deploying a WMN is neither very expensive nor difficult because of the availability of almost all the required components in the form of protocols such as ad hoc network routing, IEEE 802.11 MAC (Zhenhui Yuan et.al., 2012) (P.Venkata Krishna et.al.,2009) and Wired Equivalent Privacy (WEP) (S. Misra et.al.,2010) security. The potential and efficacy of this technology have already been recognized by several companies who offer products based on the wireless mesh networking. However, the net connectivity between the mesh clients and the mesh routers is on ad hoc basis. Such wireless networks offer motivation
to our efforts and approaches to enhance the performance of certain protocols that handles the issues of fairness, mobility and efficiency.

1.2 Mesh Architecture

The previous section illustrates the architecture of Wireless Mesh Networks (WMNs) (Ian F.Akyilidz et.al.,2005),(Nandiraju DVS., 2010) which is mostly on the basis of a fusion of MANETs and infrastructure WLANs. Fig. 1.1 illustrates a possible three-tier organization of the hierarchical architecture in the WMNs containing Internet Gateways (IGWS) (Ian F.Akyilidz et.al.,2005),(Nandiraju DVS., 2010), Mesh Routers (MRs) (Pathak P.H et.al.,2011) and Mesh Clients (MCs) (Ian F.Akyilidz et.al.,2008)(Pathak P.H et.al.,2011). A subset of MRs, termed Internet Gateways (IGWs) form the first or top tier, connected to the wired networks. These IGWs bridge the wired networks with the wireless mesh backbone and also have an exclusive interface to interact and communicate with the wired network. The second or middle tier contains comparatively a great number of wireless MRs having communication both with the IGWs and with one another utilizing a paradigm based on multi-hop communication and thus creating a wireless network of multi-hop back bone. The autonomous organization and self-healing mechanism of the MRs facilitate a dynamic addition or deletion of the network resources. MRs through the backbone network transport traffic to or from IGWs (Ian F.Akyilidz et.al.,2008) (Pathak P.H et.al.,2011) provides services to the MCs by mutually relaying each other’s traffic and facilitating interconnectivity. MRs with their inherent bridging capabilities enables WMNs to integrate with the other wireless networks in existence such as cellular, Wi-Fi (Wireless Fidelity) (P.Venkata Krishna et.al.,2009), and WiMAX (Worldwide Interoperability Microwave Access) (Misra.S et.al.,2013). The third or bottom tier addresses the requirements of the MCs or the end users, who need the network for accessing the internet and the other services including telephony, Internet Protocol etc. MRs in WMNs are generally static while the MCs are mobile largely and get registered with various MRs (Manaswi Saha et.al.,2011) at various points of time. The important factor here is that the design is similar for both the MRs and the IGWs with an exception that IGW is connected to the wired network directly whereas MR is not. The WMN can have either wired or wireless links. In WMN, it is considerably
enough if only a single subset of AP (Mina et.al.,2011) has established connection with the wired network as against the conventional Wi-Fi network which requires every AP to be connected to the wired network. The advantages of WMNs are that they need very minimal planning, moderate infrastructure and are scalable easily. In particular, WMNs can easily be deployed even in the absence of proper infrastructure or where planting of APs is difficult. In addition, only minimal infrastructure is required for setting up and deploying WMNs with few IGWs and a number of MRs. WMNs are cost effective alternatives to several other categories of networks which require very meticulous planning involving huge expenditure. Besides, the dynamic self-configuring feature in these networks enables them to extend to any number of MRs just by deploying new MRs, which accounts for their scalability. High connectivity can be achieved through the great number of MRs present in the WMN which facilitates inter-user and inter-mode multiple routes. This feature results in enhanced reliability in the transmission of data and permits adequate tolerance of fault.

Figure 1.1 Architecture of Wireless Mesh Networks (Nandiraju DVS., 2010)
1.3 State of Art

Several researches in Microsoft Research, Redmond, Silicon Valley and Cambridge are in the direction of creating such wireless technologies which permit interconnectivity among the home networks of the neighbors. Several advantages can be envisaged in establishing such connectivity and setting up community mesh networks. Testbed networks have been deployed in local apartment complexes and office buildings. Microsoft Research has a module called Mesh Connectivity Layer (MCL) (Microsoft Research Lab, 2006) where ad-hoc routing and measurement of link quality are implemented. MCL in terms of architecture is a loadable driver of Microsoft Windows. MCL utilizes a virtual network adapter which makes the ad hoc network look like an additional (virtual) link to the rest of the system. MCL routes utilize an altered version of DSR (David B et.al., 2007)(an IETF protocol) which is referred to as Link Quality Source Routing (LQSR) (David B et.al., 2007). DSR is extensively modified in order to enhance its behavior specifically to support and address the link quality metrics. An interposition layer is implemented by the MCL driver, located between the layers 2 and 3, the link layer and the network layer respectively. MCL looks like yet another Ether link, though virtual link, to top layer software. Conversely, to the bottom layer software, it seems to be another protocol implemented over the physical link.

The Broadband and Wireless Network (BWN) (Ian F. Akyildiz et.al., 2003) Georgia Institute of Technology has built a testbed in their labs for the WMNs recently. This WMN known as BWN-Mesh consists mesh routers based on 15 IEEE 802.11b/g most of which are connected to Internet testbed of next generation (also available in the BWN Lab) in such a way as to form the backhaul access to internet. The laptops and desktops with IEEE 802.11b and IEEE 802.11g cards form the testbed situated in various rooms on the same floor as the BWN Lab. Several experiments have been conducted with changes in the network topology to investigate the effects of the distance between the routers, clustering and backhaul placement along with other mobility experiments with laptops used as testbeds. The experiments with the protocols in existence (i.e., TCP, AODV, and IEEE 802.11g as transport, routing, and MAC protocols) for implementation in
BWN-Mesh testbed have amply established the performance inadequacy of these protocols with reference to throughput and end-to-end delay in WMNs. The current focus of the researches is on developing the adaptive protocols designed for transport and MAC layers, routing and the respective cross-layer design. These protocols are designed, developed and evaluated using BWN-Mesh as testbed. The application of the explored approaches in the BWN lab can be extended both to wireless sensor networks (WSNs) and to wireless sensor and actor networks (WSANs) in addition to the Wi-fi mesh networks. Supplementing this endeavor, BWN Lab attempts to integrate the present Wi-Fi mesh networks and various different wireless networks including WiMax. As a result, this integrated testbed enables the factors of the protocol design and evaluation which can be applied to several heterogeneous wireless networks such as WMNs, next generation Internet, WSNs, WSANs, and WiMAX.

The Communications Network Research Institute (CNRI) (Mark Davis et.al., 2008) at DIT (Dublin Institute of Technology) has concentrated on developing novel and innovative technologies in order to support real-time service delivery such as VoIP and streaming of videos on wireless networks especially IEEE 802.11 or Wi-Fi networks. Currently, a number of wireless mesh network challenges have been addressed by the CNRI through investigation of resource-aware routing techniques, characteristics’ measurement of 802.11 wireless links, alleviation of interference, hardware platforms for multi-radio, selection of rate, optimization of power output and fragmentation threshold tuning. The focus of CNRI (Computer Network Research Institute) is on the following areas of research interests regarding WMNs: Fast Handoff, Multi-Channel Routing, Throughput Optimization, Channel Selection, Security, Routing Overhead, and Congestion Avoidance. Three test-bed environments have been developed at CNRI for an extensive testing of their ideas in realistic scenarios. 1) 17 node test bed comprising indoor and outdoor units, 2) 5x5 grid "cabled" testbed and 3) ns-2 and OpNet simulators. This three-fold approach, fusing simulation and experiment, proves very beneficial as it offers design flexibility at various levels and validation of results.

MIT Roofnet (J. Bicket.et.al., 2005 )is a IEEE 802.11b/g mesh test-bed of experimental multi-hop which offers access to broadband internet to Cambridge M.A. Around 20
active nodes cluster in the network. The unplanned nature and the self-configuration are some salient features of Roofnet. The current research focusses measurement of 802.11 at link level, discovering routes of high-throughput regarding loss of links, adaptive selection of bit-rate, and evolving novel protocols capable of benefitting from the unique properties of radios.

In yet another test-bed, Hyacinth (Tzi-cker Chiueh et.al., 2004) developed in State University of New York at Experimental Computer System Lab (ECSL) each node makes use of multiple IEEE 802.11 radios. Thus Hyacinth is established to be a multi-channel WMN. The thrust areas of the experiments are the design factor of assignment of channel interface and routing of the packets. The concept here is that a common channel can be utilized in inter-node communication between two nodes. Multi-node inter-communication within the same channel may attract greater interference and hence, a separate channel allocation becomes necessary. Utilizing both distributed and centralized algorithm, a dynamic and intelligent channel assignment and packet routing system is proposed. Hyacinth is expected to be readily developed on the architecture of IEEE 802.11 a/b/g, and the technology of 802.16a.

CalRadio-1 and CalRadio-2 are certain other instances of testbed platforms developed at California Institute for Telecommunications and Information Technology (CalRadio., 2004) with the objective of providing platforms for wireless development. Several other academic testbeds have been designed and developed with similar objectives of addressing the issues encountered and improve the general performance of the present WMNs. There are many other academic test-beds being designed and developed, with the same goal of solving difficulties and enhancing performance for current WMNs.

Prince George Park Residences (PGPR) in Kent Ridge campus of NUS deployed an experimental testbed for outdoor use named NUS wireless mesh network. (Ben Leong et.al., 2013). The testbed is deployed where several high-rising buildings exceeding 10 store clusters in the typical urban ambience of PGPR in Singapore, with transmission environment hostile to the transmission of wireless signals. At present their mesh
network consist 20 mesh nodes situated in 20 different blocks of residence in PGPR. Every node is equipped with two Wi-Fi adapters (11abg) with wall mounted antennas in the buildings. About half the nodes are located at floor 7 and the remaining at floors 3 and 10. A three dimensional network topology is designed in this way. Steerable antennas are mounted on five of the mesh nodes. Quality of links can be optimized by a controlled reorientation of the antennas. This aspect becomes especially important in the context of 3D mesh deployment, normal in urban environment. Besides the fixed mesh infrastructure, aerial mesh nodes also have been developed utilizing the recent quadcopter technology. These aerial mesh nodes are endowed with a wide and broad range of applications including search and rescue operations. At present their fleet has three aerial nodes.

Enormous growth has been experienced in multimedia traffic in wireless communication in the recent past. One of the major issues of resource management in wireless networks is to provide Quality of Service (P.V. Krishna, 2008) to different services of multimedia on the basis of their requirement of bandwidth. But the constraints of variable and limited bandwidth make this issue of resource management for wireless networks a challenge to be addressed. Among the several available options, bandwidth adoption (C. Cicconetti et.al., 2009) is one of the best resource management methods in the process of providing QoS guarantee for varying multimedia traffic of wireless mesh networks. The salient aspect of bandwidth management is its very capacity to explore the multimedia applications for their adaptive nature and readjust their allotted bandwidth dynamically (Jiang Tang et.al., 2010). This dynamicity handles the possible fluctuations in the network resources. However, providing QoS for the traffic of multimedia is much more complicated and challenging in comparison to its wired counterpart. The issue of bandwidth continues to be the bottleneck in the context of wireless networks in spite of the high data rates offered by some of the advanced wireless technologies. In wireless networks efficient utilization of this extremely valuable and limited bandwidth resource is necessary. The purpose of allocation of bandwidth (Mesut Ali Ergin et.al., 2008) is to determine the means of bandwidth sharing among all the ongoing calls so that the diverse QoS (M.Iqbal et.al., 2010) requirements can be satisfied in the network.
It is very evident that there is a high degree of interdependence of the different individual design issues. For instance, performance of channel assignment (A. Copane et.al., 2010) requires corresponding new routing decisions in order to accommodate the modifications in connectivity. As against this, routing by itself can assist making more intelligent decisions regarding the assignment of channels. Various approaches of joint designs or cross layer designs (Ian F Akylidz et.al., 2008) (K. Nahrstedt et.al., 2005) (Lee et.al., 2011) have been proposed in order to provide optimal solutions in such scenarios. There are two broad categories of cross layer approaches namely, tightly coupled (Cheng. M et.al., 2013) and loosely coupled cross layer designs. Optimization in loosely coupled cross layer design (Cheng. M et.al., 2013) is implemented at individual layers and only then communicated to the other layers. In the mechanism of tightly coupled cross layer, the parameters of all the considered layers are taken into account for optimization. Scheduling and connection admission control in wireless mesh networks play a pivotal role in enhancing the reuse of space in order to achieve high throughput. Thus fair access is provided to the clients. The connection admission control (Hynok Lee et.al., 2010) (Bo Rong et.al., 2009) makes a logical analysis of the requests to determine its acceptance or rejection. If the request is accepted, the service flow database registers its attributes of QoS. Then, scheduling makes use of this service flow database and the algorithm of routing for scheduling of the connection in frame. Congestion (Hee-Jung Byun et.al., 2005) can be broadly defined as a condition or state occurring during the overload of network resources causing impediments to the users of the network which is objectively measured in terms of probability of loss and/or delay. The overload causes a decrease of utility in networks which support temporal as well as spatial multiplexing but with no reservation. Congestion control (Masri A E et.al., 2012) is a typical distributed algorithm that enables sharing of the resources of the network among the rival sources of traffic.

1.4 Thesis Statement

Bandwidth is a major concern in multi-hop Wireless Mesh Networks. The issue of bandwidth management with QoS-aware combined with effective methods of connection admission control as well as congestion control will be proposed and the system’s
performance will be estimated in order to encounter the challenges of bandwidth issues in WMN.

1.5 Objectives

The objective of the thesis is to offer new strategies for bandwidth optimization and utilization to be implemented in wireless mesh networks. Congestion is one of the prime factors affecting the effective bandwidth utilization in wireless mesh networks. Effective congestion management strategies in the network can achieve optimal bandwidth utilization in the aspects of delay and throughput. The following are the major objectives and thrust areas of the research:

1. To study and analyze different bandwidth management issues in wireless mesh networks.
2. To propose an effective strategy to take care of utilization of bandwidth through a cross layer model.
3. To propose an effective mechanism for congestion control to achieve higher rate of data transmission in wireless networks based on the foraging behavior of ants.
4. To propose cross layer based congestion control mechanism that takes care of the routing issues for various networks such as single source to single destination and multiple sources to multiple destinations.
5. To propose a quality-aware bandwidth-based admission control protocol for both real time and non real time traffic in wireless mesh networks.
6. To evaluate the performance of the methods developed.

1.6 Scope of the Thesis

The organization of the Thesis is as follows:

Chapter 1 Introduction: It gives a broad introduction to the concept of wireless mesh network, its architecture, existing state-of-the-art technologies, statement of the research problem, objectives and general organization of the thesis.
Chapter 2 Review of Literature Survey: This chapter discusses the prominent issues in wireless mesh networks and the related tasks of bandwidth estimation, congestion control mechanism and cross layer design for wireless mesh networks.

Chapter 3 An efficient cross layered bandwidth management framework for wireless mesh networks: This chapter illustrates the enhancement of bandwidth utilization using the quality aware cross layer design.

Chapter 4 Ant inspired level-based congestion control for wireless mesh networks: It gives the congestion control scheme based on pheromone value obtained from ant colony optimization technique. A new CRP bit has been added to the ECN-TCP header to estimate the congestion and invoke the appropriate congestion control mechanism.

Chapter 5 Cross layer-based congestion control mechanism for wireless mesh networks: It provides the congestion control mechanism for various traffic scenarios in wireless mesh network.

Chapter 6 A QoS aware cross layer-based connection admission control mechanism for wireless mesh network: It provides an effective connection admission control mechanism using a shared database model from the cross layer design for effective utilization of bandwidth for both real-time and non-real time traffics.

Chapter 7 Conclusions: It summarizes the study providing the conclusions of various proposed models.