CHAPTER 3

PROBLEM FORMULATION AND RESEARCH METHODOLOGY

The foregoing chapter has elaborated on progress, growth and development of various scheduling paradigms available for IEEE 802.16 networks. The chapter described peculiarities of these techniques and how standard has been benefitted by advances made in various scheduling disciplines. Presence of number of studies deems it necessary to analyse these studies and narrow down our focus to available gaps in these studies. The recapitulation of gaps is very important as these will act as platform for current innovations and further research in this field. This chapter will help us to formulate our scheduling problem and discuss an effective research methodology to solve it.

3.1 Gap Analysis

Work done in the field of scheduling for WiMAX PMP mode networks is a comprehensive compilation of progress made by schedulers in recent years. An attempt has been made by authors to discuss, classify and compare scheduling approaches for PMP networks. The studies explored in previous chapter justifies that scheduling problem in WiMAX networks is still on open domain for researchers in which there is still room for improvement. After critical analysis of studies done over recent past and understanding behaviour of WiMAX networks, we had listed a number of areas where one can focus to carry out further research. These areas cannot neglect progress made by industry in WiMAX equipment since its inception. The following are areas where researches can focus:

- Studies on cross layer communication based on network, application and physical layer information need to be explored further. Exploiting information available at above layers can make work of schedulers very easy as this information can help WiMAX networks to adapt to different PHY layer parameters and improve response time of schedulers.

- Scheduling shall be supported by concepts of call admission and congestion control since they go hand in hand such that more flows satisfying QoS requirements can be
admitted. A good and efficient call admission mechanism will help to admit only those flows whose QoS levels can be guaranteed.

- Effect of different routing schemes on scheduling algorithms need to be studied further. There has been negligible work in this direction. One of the few studies in this direction has been by Stephan Nosh et al. [78] who has used Interference Load Aware Routing (ILR) and Interference Load Aware Multipath Routing (ILMR) routing to improve acceptance ratio of flows. Class based scheduling is used to improve throughput and acceptance ratio of flows but still progress in this direction has been quite slow.

- Availability of simulation tools designed for WiMAX mesh mode is a major hindrance in progress of research in this direction. Simulators for PMP mode are available [79], [80], [81] however, there are not many publicly available tools that support mesh mode operation. One is available at [82] but it has drawback in its interoperability with ns-2 routing algorithms. A tool implemented on a widely used environment such as Qualnet, OPNET or ns-2 with a pluggable 802.16 mesh architecture, would be extremely useful for research community.

- Pricing issue has not been studied by any of researchers. To best of author’s knowledge no paper has been found that could have considered scheduling with pricing issues to achieve optimization of revenue and resources. All commercial implementations need this issue to be considered.

- IEEE 802.16 networks support different networks like IEEE 802.11, Ethernet etc where 802.16 can serve as backbone technology to interconnect various hybrid networks. Studies can be carried out to design schedulers to support applications for such hybrid networks.

- Majority of studies proposed have been tested without putting any restriction on size of buffers which might not be always possible. Exploration of effects on QoS of various scheduling classes can be studied by imposing restrictions on size of queues.

- Ordering and size of packets to be sent in a frame might also affect performance that is not considered, it is another area that has been left untouched.

- The problem of scheduling has been proved to be an optimization problem for which an approximate algorithm can be developed. A soft computing technique like genetic algorithm, fuzzy logic and artificial neural network can be applied whereby given
technique might be helpful in estimating, predicting or shaping traffic patterns so that decision making time of scheduler is simplified. It could be interesting to see how these techniques perform in field of scheduling for WiMAX networks. Few studies are available and authors have tried to explore them intensely but studies on fuzzy logic are still restricted. Fuzzy logic can be employed with queuing theory principles to design a dynamic and fair scheduler.

- Other allied fields can also help to provide new innovation in field of scheduling in IEEE 802.16 networks. For example, ideas from hierarchical approaches in CDMA networks and neural networks for scheduling of multiple queues[76] [77] could also be applied to IEEE 802.16 networks.
- Major emphasis has been laid on scheduling of real time classes because of their bursty and sensitive nature thereby giving unfair opportunities to non real time polling and best effort classes which might account for major traffic volume in real working environment.

The above outlined areas indicate that magnitude of scheduling problem in IEEE 802.16 networks is still large and researchers can target any of the above listed issues. Authors in current study have targeted an area in which few explorations have been made. The area that stands out from rest is application of soft computing techniques for design of scheduler in IEEE 802.16 networks. Although schedulers employing these techniques are available at [53] – [70] but fuzzy logic concepts have been sparingly exploited. Design of schedulers using fuzzy logic will be focus of research in this thesis. Next section will focus on narrowing these gaps further and eventually leading to precise definition of problem to be handled by authors in this study.

### 3.2 Problem Formulation

Soft computing is field in computer science that uses inexact solutions for computationally hard problems. Scheduling problem in WiMAX has been defined as NP complete by studies of [53] and [54]. Defining accurate solutions for such problem is practically impossible as solution space is very large but optimal solutions for these problems can be developed subject to certain constraints. There have been considerable studies by different authors who had applied soft computing approaches like artificial neural networks, genetic algorithms, game theory and fuzzy logic. These have been discussed at depth in
section 2.3.5 of Chapter 2. Of these, studies using ANN and genetic algorithms are frequently available but field of fuzzy logic has been left untouched as only few studies are available for it. Applicability of fuzzy logic to solve scheduling problem has been more appealing to authors considering nature of problem at hand. Area of fuzzy logic has been chosen for insight exploration and design of scheduler for WiMAX networks based on it is proposed in this work.

Human reasoning is not only able to make decisions and classify situations where information is partial or ambiguous. Fuzzy sets try to mimic what is natural to human reasoning, allowing imprecise definition of concepts. Few studies in this direction are available at [69] [70]. [69] has proposed downlink scheduler for inter class traffic employing two input parameters. Experiments have been conducted considering only rtPS service class with limited number of nodes. Authors of [70] had used fuzzy logic to provide dynamism to deficit round robin scheduling. They have also considered two parameters, latency of head of line packet for real time traffic and throughput for non real time flows. The fuzzy system outputs a weight value which is further used to calculate amount of bandwidth to be allocated. The above discussed studies fail to consider following issues:

- The number of input variables is limited and so is the case with number of rules used in rule-base. Both these studies have implemented their fuzzy rule bases with 15 rules.
- Sadri et al.[69] has utilized fuzzy logic for implementing downlink scheduler in WiMAX i.e. for distribution of packets to different destinations in different frames. Implementation of a downlink scheduler in WiMAX is simpler as most recent information is available in queues at BS and scheduler can use this information for sending packets to various destinations in a particular frame. The uplink aspect of WiMAX scheduling problem that is allocation of bandwidth to various SS has not been taken care of by authors. Design of uplink scheduler is a difficult task because of request-grant mechanism utilized by BS as a result of which BS can have out of time information available with it for making its scheduling decision. The proposed study focuses on development a scheduling system pertaining to both aspects of WiMAX scheduling problem.
- Alsahag et al.[70] have developed a fuzzy based scheduler to find out an optimum value for a variable that is further utilized by DRR algorithm for making allocation. The study fails to address following issues: Although a clear mechanism for devising
allocations for real time traffic are specified no such mechanism has been proposed for non real traffic. The fuzzy model used by Alsahag et al. utilizes two input parameters latency and throughput requirements for real and non-real traffic calculated on basis of bandwidth requests sent by SS to BS. However there is always a time gap between requests sent by SS and allocations made by BS. During this time gap queues serving real time traffic at SS can grow unexpectedly because of bursty nature of these classes or new applications may be admitted. The already backlogged queues of non real time classes may en-queue more packets as they have low priority as compared to real time flows.

- Both studies don’t provide any dynamism to scheduling process while [69] is static [70] is silent on dynamism and do not specify as how often weight updating will be required. Keeping the weights fixed for longer durations may degrade overall performance of system like WiMAX in which traffic statistics can change very abruptly.

- Scheduling of real time traffic done on basis of latency requirements may add unnecessarily delay to real time traffic in good channel conditions. Results of both these studies indicate unfairness to non real time classes, nrtPS and BE. Although BE does not have any QoS requirements but total amount of BE traffic in a network cannot be neglected as this class may account for 60-70% of total traffic in real environment. This factor shall be considered by new scheduler in decision making.

The approach presented in this study will try to improve upon work of [70] by designing a fuzzy based adaptive inference system. The current study will try to make allocation to different service flows on basis of most current information so that effects of applications during this request-grant gap can be minimized. The study also takes care of backlogged flows from non-real time traffic and makes sure that these shall not grow unexpectedly. This has been done by finding the instantaneous amount of traffic present in various queues in different SS and inputting these values to our fuzzy expert system. The changes, if any, in the inflow of traffic or in growth of queues will be absorbed by fuzzy system by making appropriate changes to weights serving these classes. This will result in having more fairer and adaptive allocation of resources. The round robin nature of DRR algorithm used by Alsahag et al. is also not fit for network like WiMAX where traffic is served on basis of five service classes having variable priorities and therefore authors in this study have decided to
use more efficient and fairer WFQ algorithm. DRR also puts a limitation that only one packet from each queues can be served in one round which makes it unfair to small sized flows.

A system will be developed working on three input and single output variable. The three input variables namely latency for real time traffic, throughput and queue length share for non real time traffic will be considered and queue weight being single output variable. The other focus of improvement apart from satisfying QoS requirements of various classes will be providing fairness to all traffic flows. This will be implemented by choosing fairer Weighted Fair Queuing algorithm instead of Deficit Round Robin. WFQ is fairer to all classes as it considers not only priority of service class but packet size also while making allocations. The second focus of improvement for this study is to increase overall and performance of non real time traffic classes. This will be done by making system adaptive to variations in traffic for both real and non real time service classes so that changes in traffic variations are absorbed by respective weights of queues handling these service classes quickly. The system will be made adaptive by extracting input parameters during network simulations. These extracted parameters will be inputted to fuzzy system and new weights will be calculated for bandwidth request received by base station. This will help in honouring more number of bandwidth requests by scheduler in good channel conditions that will lead to improvement of overall throughput of system. Improvement of non real time classes will be made by introducing third input variable, change in queue length for non real time traffic. The sole aim of this variable is to avoid starvation of low priority non real time classes at peak network loads. This will also help in getting allocations from BS when there are not stringent real time requirements. Total number of rules in rule base has also been increased to 45 which this will help in imparting more diversity to decision making process of our scheduler.

3.3 Research Design

Research design is a strategy, a plan and a structure for conducting research. It is comprehensive master plan of research study to be undertaken, giving a general statement of methods to be used. Selection of research design is to ensure that requisite data is in accordance with the problem at hand and is collected accurately and economically. It is framework or blueprint for research study that guides collection and analysis of data. Research design depending upon needs of researcher may be a detailed statement or only furnishing of minimum information required for planning research project. Every design has its positive
and negative sides and best design depends upon research question as well as orientation of researcher. Various modes of research design are: Theoretical research design, applied research design, exploratory design, descriptive design, quasi-experimental design and experimental design.

Present research is based on exploratory, experimental and applied research design. It is exploratory as it consists of discovery of new ideas and possible insights in identifying areas of further study. It is experimental as data discovery of new findings is supported by conducting experiments and evaluations are done on network simulator which is universally accepted and these findings can be verified also. The research problem undertaken in this study is industry specific therefore it falls under the category of applied research design. Data for sake of research study has been generated by simulators using various mathematical distributions. Inbuilt tools of simulator have been used for data generation. The simulator to be used is developed by an independent international proprietary organization which is certified and widely used in research, security by government organizations across the world. Utilization of generated data is done by designing scheduler for IEEE 802.16 networks which extracts information from data during simulations and helps to achieve our primary objective of handling diverse traffic applications. The authenticity of work is also supported by comparing designed work with standard approaches. Next section elaborates upon various steps followed by authors to develop proposed system.

IEEE 802.16 standard, its growth, working, packet formats and working of uplink scheduler has been studied. Analysis of latest studies in this field has led to decision of design of scheduler based on concepts of fuzzy logic. The designed system will be fully automated and fully adaptive to variations in traffic. WiMAX is inherent to provide support to number of applications in today’s environment. These applications generate mix of real and non real time traffic in abundance. Requirements of these applications are very assorted; therefore system will be designed keeping requirements of these applications and bandwidth allocation policy of WiMAX in mind. Input and output variables have been chosen in accordance with traffic properties and to overcome limitations of already available studies. Input variables that are considered are latency for real time traffic, throughput requirement for real and non real time traffic and queue length share for non real time traffic. Choice of first two variables is self justifying as these are chosen in accordance to properties and requirements of traffic types supported in WiMAX. Third variable is chosen so that queues in non real time traffic
classes do not grow infinitely and scheduler is able to devise strategy to prevent non-real-time classes from getting starved. Output variable is taken as weight of queue serving real or non-real traffic. Effects of variations in traffic load for real and non-real time applications will be absorbed by weights of respective queues. This weight will be used for making allocations to traffic classes on basis of technique described in upcoming chapters. The proposed technique considers time requirements for real-time traffic and initial priority for non-real-time traffic to make allocations. Various membership functions are defined on the basis of the corresponding variables and 45 different if else rules are created for fuzzy rule-base.

WiMAX is an upcoming technology and its support in terms of hardware is limited and expensive therefore proposed scheduler will be implemented on a simulator. Qualnet Developer 5.2 has been chosen for implementation as it is distributed with advanced wireless library providing support for implementing WiMAX networks. It also comes with features where users can embed their own source code to enhance its existing features. Scheduler developed on concept of fuzzy logic will be programmed into Qualnet simulator and WiMAX networks will use fuzzy based scheduler as their default scheduler. The proposed technique will be compared with already established techniques like weighted fair queuing, weighted round robin and earliest deadline first algorithms.

### 3.3.1 Working Flow of System

A sample WiMAX network will be setup in Qualnet 5.2 simulator consisting of one or more number of base stations and multiple subscribers working in PMP mode on which different applications will run. The classier available at BS will classify incoming traffic into data packets or bandwidth request packets and sends these packets to different queues. Developed scheduler at BS will analyse respective queues of different classes and values of input parameters will be extracted from these queues during simulations. The parameters extracted will be inputted to fuzzy inference system. The fuzzy inference system has been designed consists of 45 rules varying over 3 inputs and single output. There will be total of sixteen different membership functions defined for both input and output variable. The fuzzy system will yield a value on basis of input values of parameters and fuzzy rule-base. This value will be considered as weight for queues of real-time traffic and will be used to allocate number of slots to real-time traffic. Experiments will be conducted to justify usefulness of proposed method. The proposed approach will be validated by comparing with standard practices in the related field.
3.4 Limitations of Study

The work proposed in this study is novel contribution made by authors to develop a scheduler for IEEE 802.16 networks. Work done in this thesis has been undertaken keeping in mind recommendations of IEEE 802.16 standard however few assumptions and limitations of this study may be outlined as under:-

- Presence of call admission and control mechanism has been assumed as scheduler shall not be affected by increase in number of connections.
- Only logical allocation of scheduler has been considered, means, we had considered number of slots to be allocated to different SS where as selection of sub-channels with suitable time periods is not done as it deals with PHY aspects of IEEE 802.16.
- Orthogonal Frequency Division Multiple Access (OFDMA) physical layer specification has been considered as scheduler is not tested for other PHY implementations.
- Piggybacking of bandwidth requests opportunities is not considered.
- Assumption of ideal channel conditions and no interference from weather or other sources has been considered.
- Packet header compression is not implemented. Although this does not directly affect working of scheduler but it is a consideration when reading throughput numbers.
- Priorities among various connections within same scheduling type are not considered.
- No restrictions on buffer capacities have been put at user level.

3.5 Chapter Summary

This chapter has listed out number of gaps which are left uncultivated by available studies on scheduling of IEEE 802.16 networks. Presence of these gaps is an indication about multi dimensionality of the problem at hand. The analysis of gaps has enabled us to narrow down scheduling problem to specific domain and focus on solving it with help of soft computing approaches using specifics of fuzzy logic. Formulation of problem and its statement has been made in this chapter and problem will be solved by designing a fuzzy based framework consisting of three input and one output variables. The working model and research methodology adopted for design of this schedulers is also discussed. Every study is completed within certain limitations and the chapter ends by listing these limitations.