Measurement-based Admission Control for Real-Time Traffic in IEEE 802.16 Wireless Metropolitan Area Network

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

To support real-time applications, we present a Measurement-based Admission Control (MBAC) scheme with Modified Largest Weighted Delay First (M-LWDF) scheduling algorithm.

The objective of the admission control scheme is to admit new real-time application call into the system without jeopardizing the maximum average packet delay bound. Measured values of the average packet delay from the network are used for the admission decision. As long as a new call can obtain the requested service and the packet delay of existing calls are not risked by admitting it, the new call will be accepted into the network. In addition, M-LWDF scheduling algorithm is introduced to efficiently allocate network resource. Simulation results show that the proposed MBAC scheme maintains good packet delay bound.

Acknowledgements

I would like to extend my deep thanks and appreciation to my supervisor Professor Sherman Shen for his support and positive feedback. Having no background in both Electrical and Computer Engineering and Communication and information Systems was a challenge for me. I would not have made it this far without the help of God then without professor Shen's deep knowledge and intellectual discussions. I would like to also thank Professor Liang-Liang Xie and Professor Zhou Wang for all their support, discussions, and advice. Last but not least, I thank my colleagues for all their help. The knowledge that I have gained from my masters program will be very beneficial for me in my future research and career thereafter.

To my parents...

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List of Symbols

$MBAC$	Measurement-based Admission Control	iii
M − LWDF	Modified Largest Weighted Delay First	iii
QoS	Quality of Service	1
CAC	Call Admission Control	2
RRM	Radio Resource Management	2
MAN	Metropolitan Area Networks	2
WiMAX	Worldwide Interoperability for Microwave Access	2
DSL	Digital Subscriber Line	2
MAC	Medium Access Control	3
PBAC	Parameter-based Admission Control	3
PMP	Point-to-Multipoint	8
BS	Base Station	8
SSs	Subscribers	8
TDMA	Time Division Multiple Access	9
UGS	Unsolicited Grant Service	9
rtPS	Real-time Polling Service	9

MPEG	Moving Pictures Experts Group	9
nrtPS	Non-real-time Polling Service	9
BE	Best Effort Service	9
GC	Guard Channel	20
FG	Fractional Guard Channel	20
CDMA	Code Division Multiple Access	21
FDMA	Frequency Division Multiple Access	21
EDF	Earliest Deadline First	24
MS	Measured Sum	27
HB	Hoeffding Bounds	27
TP	Tangent at Peak	27
MC	Measure CAC	27
TE	Traffic Envelope	27

Chapter 1

Introduction

Wireless networks have significantly impacted the world and are vital to every facet of life. The manifestation around the clock information access is being realized with the vast expansion of wireless communication technologies. A tremendous evolution in wireless networks, from cellular systems reaching out to broadband Wireless Wide Area Networks (Wireless WAN), has taken a place. This evolution accommodates user needs from one individual to large landscapes ranging from industrial, educational, artistic and to political.

With the rapid growth of wireless communication systems, the number of wireless users have consequently increased. Therefore, wireless networks should be able provide guaranteed quality of service (QoS) for different services while maintaining high network utilization. Indeed, when designing wireless networks, it should be understood that these two competing requirements (QoS and network utilization) necessitate an efficient algorithm to obtain a good balance between them [1]. Furthermore, the concurrent transmission by network users causes interference, which may instigate the users to race for limited resources of the wireless network. To cope with these challenges, proper management of available radio resources is vital in such a heterogeneous wireless network supporting multiple types of applications with various QoS requirements. The wireless network may also have to decline new call/connection if the resources are not available or this new call/connection would violate the network promises. The process of such decision is called call admission control (CAC) .

CAC is considered as one of Radio Resource Management (RRM) techniques. RRM is a set of methods that manage the usage of radio resources and intends to assure QoS and maximize the overall system capacity [2]. In general, RRM can be categorized into the following elements: hand off and mobility management, CAC, load control, channel allocation and reservation, and scheduling [2]. In this thesis, we propose a CAC for IEEE 802.16 Wireless Metropolitan Area Networks (Wireless MAN) to support real-time traffic. IEEE 802.16, also known as the Worldwide Interoperability for Microwave Access (WiMAX) , gains its attraction from the cost-effective, promising technology for “last mile” connectivity at high data rates in areas beyond the reach of Digital Subscriber Line (DSL) and cable. IEEE 802.16 aims to provide the desired QoS for different levels of traffic with high speed broadband wireless connectivity. Hence, QoS in IEEE 802.16 has become a challenging issue. Moreover, utilizing the limited radio spectrum resources and improving system performance are playing an essential role in deploying efficient resource utilization for IEEE 802.16. Although the physical layer specifications and the Medium Access Control (MAC) protocol signaling are specified and defined in the standard, IEEE 802.16 Wireless MAN does not specify RRM techniques such as CAC. Therefore, designing a talented CAC algorithm has become an interest of many researchers and thus the provisioning of QoS for IEEE 802.16 network presents a challenging demand.

1.1 CAC Schemes in IEEE 802.16

"CAC is an algorithm that manages radio resources in order to adapt to traffic variations" [1]. The objective of CAC is to maintain a certain level of QoS to the different calls by limiting the number of ongoing calls in the network. CAC in wireless networks is more complicated than wireline networks due to the unique features of wireless networks such as multiple access interference, channel impairments, handoff requirements, and limited bandwidth [3]. In general, when a user initiates a connection or when a new service is added during an ongoing call, admission control is operated [1]. A new call is admitted into the system if the network has sufficient resources to guarantee the QoS that the user requests without violating the QoS of existing calls in the network. Furthermore, the admission control scheme attempts to keep the interference below some threshold after a new call has been admitted [1].

CAC algorithms can be categorized as Parameter-based Admission Control (PBAC) or Measurement-based Admission Control (MBAC). The PBAC scheme calculates the amount of system resources required to maintain a set of flows based on a prior flow of traffic descriptions in terms of the parameters of a deterministic or stochastic model [4]. The admission decision is then based on the specifications of ongoing and new connections. The parameter-based approach offers assured QoS but often yields low network utilization [5]. In MBAC scheme, on the other hand, admission control decisions are made based on network measurements of actual traffic loads. The behaviour of the existing calls is observed rather than assuming a statistical or worst-case model for the traffic where this information is used to make admission decisions.

1.1.1 MBAC

"MBAC is an attractive mechanism to concurrently offer QoS to users without requiring a priori traffic specification and online policing" [6]. Comparing MBAC mechanism to support real time traffic and traditional real-time methods, the traditional real-time service provides a hard bound on the delay of every packet [7] in which admission control algorithm uses worst-case analytical bounds as its basis [8]. Because of the bursty nature of network traffic, these types of admission control schemes normally suffer from low network utilization. MBAC; however, can achieve potentially better network utilization [8]. Real-time applications are delay and loss sensitive, yet they can bear some loss and delay; therefore, they are tolerant of occasional QoS violations. Consequently, efficiency in achieving high network utilization can be granted by using the MBAC. MBAC uses actual traffic load measurements and QoS performance to make admission control decisions in which a new call will be rejected if there is no available bandwidth to accommodate it; otherwise, accepting the new call will violate the QoS of the existing calls. MBAC provides a good network utilization and predicted QoS where the network will attempt to assure the requested QoS; nevertheless, it will not provide any guarantee [9]. Real-time applications mostly have adequate adaptability to actual packet delays and are tolerant of occasional delay bound violations; consequently, they do not necessitate a hard reliable bound. Therefore, real-time applications should utilize the MBAC advantages for their benefit.

1.2 Contribution

In this thesis, we will present a MBAC algorithm with M-LWDF scheduler [10]. Particularly, MBAC is designed to be deployed in wireless MAN (IEEE 802.16) to support real-time traffic. The M-LWDF scheme is effectively designed to support real-time traffic in wireless networks in term of the packet delay. M-LWDF maintains the delay of each traffic flow below a predefined threshold value; moreover, it takes the instantaneous channel quality experienced by the user into account. The proposed scheme is to enhance M-LWDF functionality in terms of QoS. In particular, our MBAC is to ensure that the feasibility of QoS provisioning by M-LWDF scheduling scheme is held. Basically, new calls requests will be denied if packet delays experienced by the existing users are close to the delay deadline.

1.3 Outline

The reminder of this thesis is organized as follows:

Chapter 2 presents an overview of IEEE 802.16 standard. Also, the fundamentals of CAC approaches in wireless networks and IEEE 802.16 are presented, which include:

1. The purpose of CAC algorithms
2. Some major challenges in the design of CAC schemes for wireless networks
3. Basic components of CAC and the classifications of CAC schemes
4. CAC for QoS provisioning in wireless networks
5. CAC schemes in IEEE 802.16 wireless MAN
6. MBAC schemes

The proposed CAC scheme is introduced in chapter 3 as follows:

1. The design goals and structure of our MBAC
2. The deployment of the admission control to work along with M-LWDF in order to enhance its functionality in terms of QoS
3. The advantages of the proposed scheme and the design challenges

Simulated analysis of the proposed scheme is presented in Chapter 3 section 3.3 in order to demonstrate its efficiency in providing QoS for real-time applications.

Conclusion and future work are presented in Chapter 4.

Chapter 2

Background and Literature Review

2.1 IEEE 802.16: Broadband Wireless MAN Standard (WiMAX)

IEEE 802.16 standard offers broadband wireless access technology, which provides high-speed networking with QoS guarantee for various applications. Apart from that, IEEE 802.16 gains its attraction from the cost-effective promising technology for last mile connectivity at high data rates in areas beyond the reach of DSL and cable. IEEE 802.16 aims to provide the desired QoS for different types of traffic with high speed broadband wireless connectivity, particularly for real-time application. in IEEE 802.16, CAC is very important technique to support QoS provisioning; However, IEEE 802.16 Wireless MAN does not specify CAC techniques although the physical layer specifications and MAC protocol signalling are specified and defined in the standard. Therefore, designing CAC algorithms have been left to vendors. In the next sections, we provide

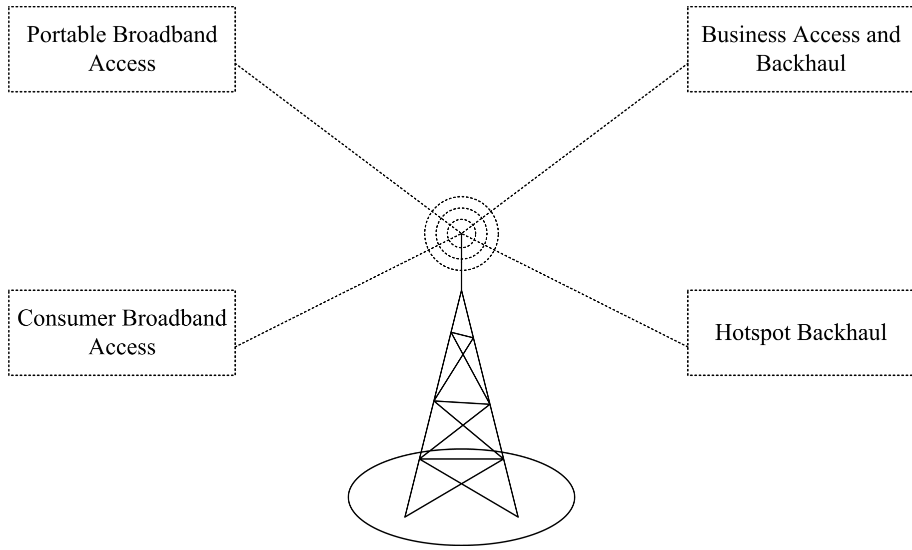

Figure 2.1: Wireless MAN

overview of IEEE 802.16 standard and discuss the need for CAC methods in wireless networks.

IEEE 802.16 standard [11] defines the air interface and MAC protocol for a wireless MAN, operating at 10 to 66 GHz, which is proposed for providing high-bandwidth wireless voice and data. Multilevel QoS for real-time and non-real-time traffics is supported by the standard where mobility is considered in the IEEE 802.16e.

In IEEE 802.16 standard, nodes are classified into a central base station (BS) and subscriber stations (SSs) as in figure 2.1. Two different models for sharing the wireless medium are specified: point-to-multipoint (PMP) and mesh. PMP mode rigorously requires all SSs to associate with a BS as is shown in figure 2.2 [12]. On the other hand, mesh mode enables the mesh deployment where a direct communication between the neighbouring SSs is possible as it can be seen in figure 2.3 [12]. In the PMP architecture, the connection between the BS and SSs is set up in both downlink (from BS to SS) and uplink (from SS to BS) directions. The communication among SSs is not direct since the BS schedules the traffic flow in the wireless environment. The uplink channel is shared by all SSs where SSs access the channel through time division multiple access (TDMA). Conversely, the downlink channel is in broadcast mode. In figure 2.4 [13], a typical frame structure in IEEE 802.16 is shown. A frame is composed of downlink subframe and uplink subframe where the length of these subframes is specified by the BS.

To support QoS, four types of service flows defined in IEEE 802.16 are described as follow:

- Unsolicited grant service (UGS) is designed to support constant bit-rate (CBR), such as Voice over IP [11].

- Real-time polling service (rtPS) is designed to support real-time varible bit-rate (VBR), such as moving pictures experts group (MPEG) video [11].

- Non-real-time polling service (nrtPS) is designed to support non-real-time applications, such as FTP [11].

- Best effort service (BE) is designed to support best effort traffic such as HTTP [11].

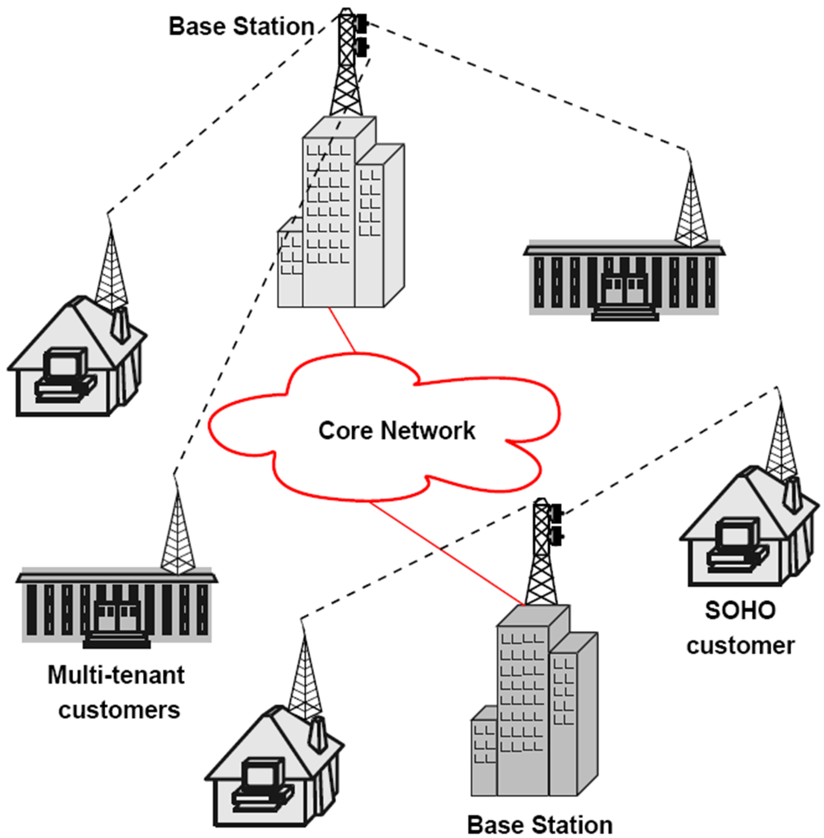

Figure 2.2: PMP mode

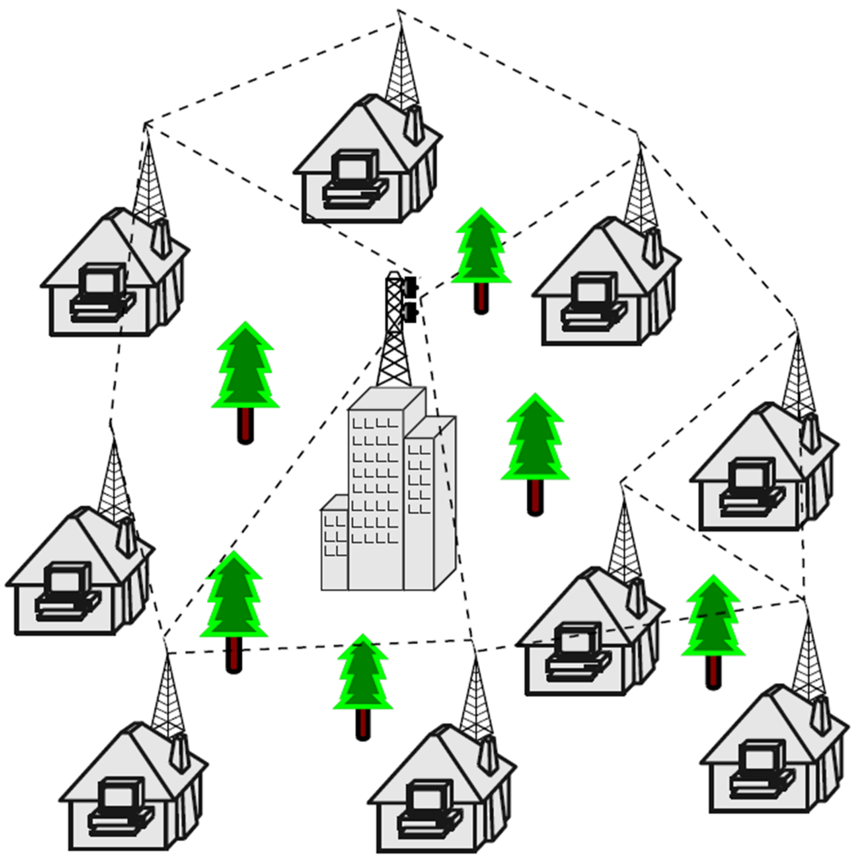

Figure 2.3: Mesh mode

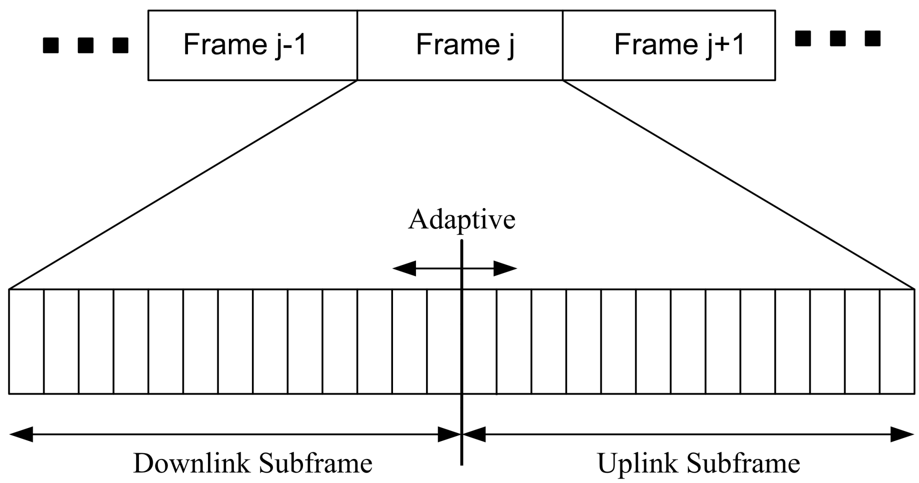

Figure 2.4: The IEEE 802.16 frame structure

2.2 The Need of CAC in Wireless Networks

With the rapid growth of wireless communication systems, the number of wireless users have consequently increased. Therefore, wireless networks should be able provide guaranteed QoS for different services while maintaining high network utilization. Indeed, when designing wireless networks, it should be understood that these two competing requirements (QoS and network utilization) necessitate an efficient algorithm to obtain a good balance between them [1]. Furthermore, the concurrent transmission by network users causes interference, which may instigate the users to race for limited resources of the wireless network. To cope with these challenges, proper management of available radio resources is vital in such a heterogeneous wireless network supporting multiple types of applications with various QoS requirements. The wireless network may also have to decline new call/connection if the resources are not available or this new call/connection would violate the network promises. The process of such decision is called CAC.

"CAC is an algorithm that manages radio resources in order to adapt to traffic variations" [1]. The objective of CAC is to maintain a certain level of QoS to the different calls by limiting the number of ongoing calls in the network. CAC in wireless networks is more complicated than wireline networks due to the unique features of wireless networks such as multiple access interference, channel impairments, handoff requirements, and limited bandwidth [3]. In general, when a user initiates a connection or when a new service is added during an ongoing call, admission control is operated [1]. A new call is admitted into the system if the network has sufficient resources to guarantee the QoS that the user requests without violating the QoS of existing calls in the network. Furthermore, the admission control scheme attempts to keep the interference below some threshold after a new call has been admitted [1].

Many aspects of designing admission control mechanisms in wireless network show the natural tension among simultaneous calls and demonstrate the challenge in designing a CAC. First, the network must deal with two types of calls: new calls and handoff calls. From the user's point of view, forced termination of an in progress call is less wanted than the blocking of a new call [14]. Hence, to sustain reasonable levels of call dropping and blocking rates, network should consider prioritization or reservation algorithms [15]. Second, the network should assign varied priority services to many classes of traffic with different QoS requirements [1]. Finally, it is the network's responsibility to provide fair access to the network resources for all users; therefor, fair resource allocation and QoS satisfaction to all the users must be achieved at the same time [1].

The rest of the chapter is organized as follows: The purpose of CAC algorithms is discussed in the next section. Some major challenges will be discussed in Section 2.4. Basic components of CAC and its classifications are introduced in section 2.5 and 2.6, respectively. In Section 2.7, a survey of the traditional CAC schemes is investigated; section 2.8 discusses CAC schemes in IEEE 802.16 Wireless Metropolitan Area Network and MBAC approach is presented in section 2.9. Finally, the summary is given in Section 2.10.

2.3 The Purpose of CAC Algorithm

In wireless networks, CAC is very important to manage the use of the shared network among different service types. Besides the main objective of admission control, which is to regulate the admission of new users into the system while guaranteeing the user requirements for communication quality of the existing users without leading to call dropping [1], many purposes of an admission control vary in term of the design principles as indicated in [3]. For example, in interference-limited wireless networks, CAC is used to ensure the signal quality. A further example of the objective of CAC is to guarantee a minimum transmission rate in wireless networks supporting data service. Also, the issue of fairness among services have been taken into account in designing some CAC schemes. Another goal of admission control is to give different priority to different services or to optimize the network revenue. These schemes are discussed in detail in Section 2.7.

2.4 Major Challenges

Wireless networks are complicated systems and many issues must be considered in the design of appropriate CAC schemes for efficient resource allocation. Several challenges in wireless systems have been summarized as follows.

2.4.1 The Limitations of Wireless Media

Although using radio technology to launch networks is mainly considered an advantage, when designing a network, it adds a new level of complexity for the network engineers. Due to the limitation of radio resources (i.e., physical and regulatory restrictions) in addition to the interference-limited nature of wireless systems, efficient schemes for sharing the radio spectrum are needed to provide communication service with high capacity and desired QoS.

2.4.2 Mobile Environment and Handoff Events

When a mobile terminal travels from one cell to another while a call proceeds, the channel in the old BS is released and a channel is requested in the new BS. The handoff will fail if there are no enough channels in the new cell to accommodate it, which is greatly undesirable [16]. By reserving some channels for handoff calls, handoff

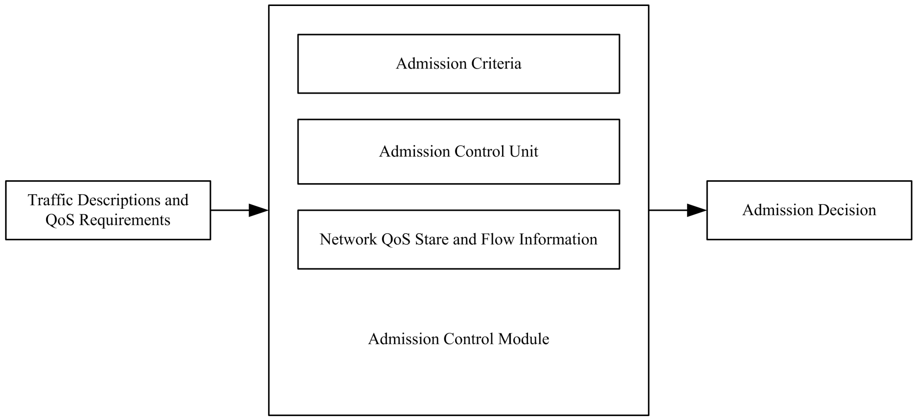

Figure 2.5: Components of admission control

failure rate can be reduced. On the other hand, the call blocking rate may increase due to such bandwidth reservations; therefore, reduction of handoff failure rates and call blocking rates are conflicting requirements, and balancing of both is extremely complex.

2.4.3 Multiple Classes Types

One of the challenges encountering network engineers is the ability to support multiple classes of traffic with different QoS requirements. Different applications (e.g., voice, video, data and multimedia traffic) need to be supported with differing service guarantees in wireless systems, while optimizing network resource utilization, is required.

2.5 Basic Components of Admission Control

CAC algorithms extract its decision based on the collaboration of three basic components. As shown in figure 2.5 [17], traffic descriptor, admission criteria, and network QoS state and flow information are the fundamental architectures of a CAC scheme. These three components are in cooperation with each other in order to achieve specific CAC objectives such as controlling the signal quality or call dropping probability.

An admission control module obtains the traffic descriptor and the QoS requirements of the flow as its inputs, and outputs its decision of either admitting the flow at the demanded QoS or denying it if that QoS is not met [18]. A traffic descriptor is a set of parameters of the source that describes the traffic characteristics. In order to obtain the admission control decision, the admission controller consults the admission criteria module, which is a set of rules used by the CAC scheme to make the decision [19]. Since the wireless channel is a shared medium among users, the influence of a new call on the exciting calls should be considered. Consequently, a new call would be denied if it has a bad effect on other calls and the utilization target of the network.

2.6 Classification of CAC

The admission control schemes proposed in the literature can be classified by a number of properties. Some of these properties are shown in figure 2.6. They can be branded based on diverse criteria. Each criterion has its advantages and disadvantages. For example, a CAC algorithm can function in either a centralized or distributed way. In

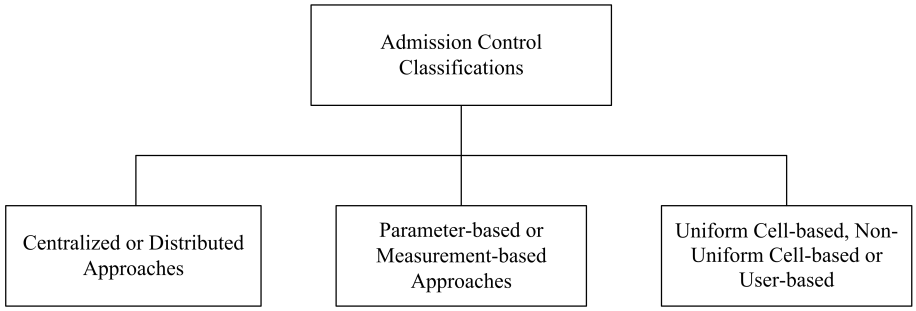

Figure 2.6: Classification of CAC

the centralized mode, a CAC scheme is implemented in a central site, while in a distributed scheme, CAC is performed locally at the BS of each cell. Although distributed admission control has benefits, it is less efficient than the centralized scheme.

CAC algorithms can be categorized as Parameter-based Admission Control (PBAC) [20] or Measurement-based Admission Control (MBAC). The PBAC scheme calculates the total of network resources required to accommodate a set of flows given prior flow traffic characteristics in terms of the parameters of a deterministic or stochastic model [21]. The admission decision is then based on the specifications of ongoing and the new connections. The parameter-based approach offers assured QoS but often yields low network utilization. In MBAC schemes [22], admission control decisions are made based on network measurements of actual traffic loads. The behaviour of the existing calls is observed rather than assuming a statistical or worst-case model for the traffic where this information is used to make admission decisions.

The last design criterion used in CAC schemes is based on the information gran-

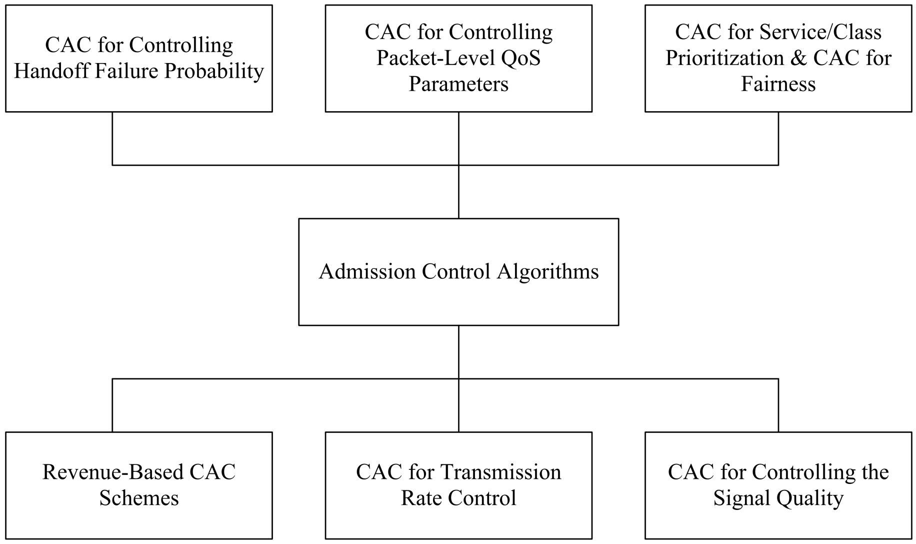

Figure 2.7: Traditional CAC Algorithms in Wireless Networks

ularity which can be considered at the cell level or the user level [3]. Information of one cell is sufficient to characterize the network state if a uniform traffic model is assumed; conversely, the information size would be increased in case of a non-uniform traffic model(since information from different cells is necessitated to model the network condition) or in case of information of each individual user is considered [3].

2.7 CAC for QoS Provisioning in Wireless Networks

There are many motivations why admission control is necessitated. The most important reason; however, is to guarantee QoS. In [3], the author indicates the main reasons for using CAC schemes as shown in figure 2.7.

Maximizing the resource utilization in wireless networks based on the availability of wireless spectrum is very vital. However, from the SSs of wireless networks point of view, taking the effect of handoffs into account is an important factor. In other words, forced termination of a call in progress is more frustrating than blocking of a new call [14]. Thus, treating new calls and handoff calls differently should be considered by prioritizing handoff calls over new calls. To obtain scalability, a tradeoff has to be made between reducing handoff call and new call blocking probabilities.

Different mechanisms of CAC for controlling handoff failure probability are investigated in the literature. These approaches include the Guard Channel (GC) policy [23], Fractional Guard Channel Policy (FG) [24], and the virtual connection tree concept [4]. GC policy, initially introduced by Hong and Rappaport in [23], became a well-known approach which reserves a number of channels to handoff calls. Specifically, an amount of channels, called Guard Channels, is reserved by the GC policy and specified for handoff calls (let say C-T). The GC policy starts to decline new calls when the channel occupancy goes beyond a certain threshold T until the channel occupancy becomes below T [25]. This policy admits handoff calls as long as channels are available.

For multimedia service in wireless networks, offering guaranteed packet-level QoS is very essential. This can be obtained by providing QoS in terms of packet delay, delay jitter, and packet loss probability. In [26], the CAC scheme uses mobility information to estimate future requirements and available resources, and provides service priority to handoff calls by booking amount of channels exclusively for handoff calls. As a criteria for CAC, The authors used packet delay upper bounds for variable bit rate calls, and jitter for all constant bit rate calls. If both packet delay and delay jitter can be guaranteed, the call is accepted, otherwise, it is rejected.

Several studies on QoS support in wireless networks have addressed the service differentiation by adopting different admission criterion for each service. For example, in [26], admission control is implemented by reserving resources for classes with high priority and then to those with low priority. As long as the reserved resources for specific classes are sufficient, the call is admitted. Optimizing the network revenue is another purpose of admission control as in [27] and [28]. An important admission control criterion in wireless multimedia networks addresses how to achieve fairness in the aspects of bandwidth utilization [29] and QoS for multiple classes of traffic [20]. Another use of the CAC schemes is the guarantee of minimum transmission rates. Limiting the network loading is a way to afford a minimum transmission rate. A maximum value of the number of users per cluster is allowed where all accepted calls enjoy a minimum transmission rate even when they travel to any of the surrounding cells [30].

In Code division multiple access(CDMA) systems, the design of a CAC algorithm is more challenging than that in hard-capacity systems such as a TDMA or Frequency Division Multiple Access (FDMA) network due to the dependence of CDMA capacity on interference contributed by every call in neighbouring cells [31]. In other words, network capacity is bounded by the maximum tolerable interference in the network [32]. Admission algorithms, based on the assumption of time-invariant cell capacity, used in hard-capacity systems may possibly reduce the system utilization in a CDMA system [33]. Therefore, a new call request is denied if it brings in extreme interference into the system [34].

In [3], CAC for controlling the signal quality can be implemented in different approaches. For instance, with Interference and SIR-based CAC [35] [36] [37], a new call is accepted if the interference level (SIR) is less (greater) than a predefined threshold value. Also, by using the effective bandwidth concept, determining the maximum number of admissible users is an efficient way to control the signal quality [38].As an admission policy, some CAC schemes admit new calls by using the total transmitted/received power [39]. Finally, in [40], the new call is accepted if a feasible power allocation is obtained.

2.8 CAC in IEEE 802.16 Wireless Metropolitan Area Network

IEEE 802.16 is a promising technique for providing broadband wireless access with QoS guarantee. Apart from that, IEEE 802.16 gains its attraction from the cost-effective promising technology for "last mile" connectivity at high data rates in areas beyond the reach of DSL and cable. IEEE 802.16 aims to provide the desired QoS for different types of traffic with high speed broadband wireless connectivity, particularly for real-time application. In IEEE 802.16, CAC is very important technique to support real-time applications QoS provisioning; However, IEEE 802.16 Wireless MAN does not specify CAC techniques although the physical layer specifications and MAC protocol signalling are specified and defined in the standard. Therefore, designing CAC algorithms have been left to vendors. In the next part, we provide an overview of CAC schemes in IEEE 802.16.

Many research has been conducted on CAC schemes for IEEE 802.16 to provide desirable QoS for real-time application in terms of packet delay performance [13] [41] [42] [43] [44]. For instance, Kitti Wongthavarawat, and Aura Ganz [13] proposed an uplink scheduling algorithm and admission control policy for IEEE 802.16 broadband wireless access standard. It guarantees QoS in terms of both bandwidth and delay for all traffic classes. A new call will be accepted as long as there is sufficient bandwidth to accommodate it. QoS for the new connection will be guaranteed and the new connection will not degrade QoS of existing connections.

Many algorithms have been presented in order to support the delay requirements for real-time applications. These algorithms can be broadly classified into the following categories:

The Game-theoretic Approach

For instance, in [41], a game-theoretic framework for admission control in IEEE 802.16 network was proposed. Based on a queuing model, delay performance for real-time traffic has been analyzed. As long as an equilibrium can be reached between the two players (the BS and a new connection), the new connection will be accepted.

The Token-bucket Based Approach

In [43], a token-bucket based uplink packet scheduling combined with CAC has been proposed. The traffic has been characterized by the token rate estimation model which converts Poisson traffic flow into token bucket based connection. The objective of the CAC and uplink packet scheduling is to assure the delay requirement of rtPS flows in which the model can predict the delay and loss of a traffic flow accurately. The CAC algorithm calculates the available bandwidth. Upon the arrival of a new call, the required bandwidth by this call will be estimated; based on this the system will decide to admit this new call or not. $r_i + \frac{d_i}{(m_i-1)*f}$ is used to estimate rtPS flow bandwidth where r_i is the token rate, f is the frame length and d_i is the delay requirement; for the other three flows (UGS, nrtPS, BE) , r_i , the token rate, will be used to estimate bandwidth [43].

Earliest Deadline First (EDF) Concept

In order to support the QoS requirements of real-time video applications in IEEE 802.16 networks, a combined CAC and scheduling algorithm based on the concept of EDF has been proposed by O. Yang and J. Lu in [44]. The scheme notably succeeds in providing good throughput improvement with acceptable delay and fairness requirements among SS.

Optimization-based Approach

A joint adaptive bandwidth allocation and connection admission control method for real-time and non-real-time polling services has been presented in [42]. The approach for resource allocation and connection admission control has been formulated as an optimization problem where delays for real-time and transmission rate for non-real-time polling services have been used in the optimization problem as decision criteria. Based on the solution of the optimization formulation, admission control is performed in which an incoming connection will be accepted/rejected if the solution is feasible/infeasible. This scheme shows good results compared to traditional static and adaptive bandwidth allocation schemes; however, with the increase of number of connections, the computational complexity of the problem increases very rapidly.

2.9 MBAC

"MBAC is an attractive mechanism to concurrently offer QoS to users without requiring a priori traffic specification and online policing" [6]. Comparing MBAC mechanism to support real time traffic and traditional real-time methods, the traditional real-time service provides a hard bound on the delay of every packet [7] in which admission control algorithm uses worst-case analytical bounds as its basis [8]. Because of the bursty nature of network traffic, these types of admission control schemes normally suffer from low network utilization. MBAC; however, can achieve potentially better network utilization [8]. Real-time applications are delay and loss sensitive, yet they can bear some loss and delay; therefore, they are tolerant of occasional QoS violations. Consequently, efficiency in achieving high network utilization can be granted by using the MBAC. MBAC uses actual traffic load measurements and QoS performance to make admission control decisions in which a new call will be rejected if there is no available

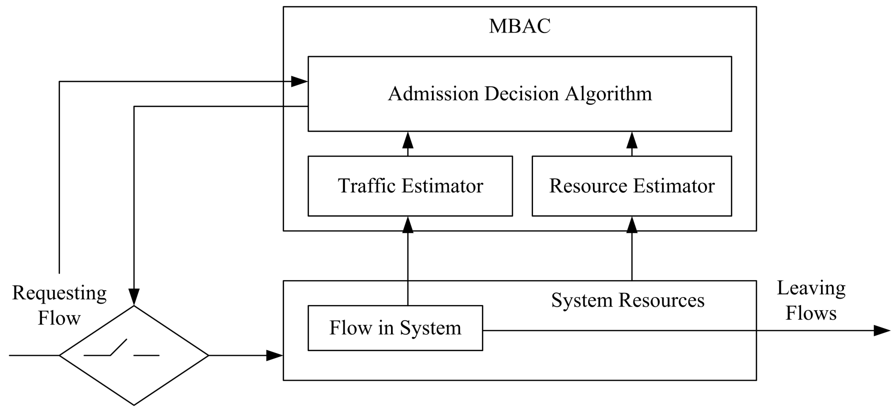

Figure 2.8: MBAC structure

bandwidth to accommodate it; otherwise, accepting the new call will violate the QoS of the existing calls. MBAC provides a good network utilization and predicted QoS where the network will attempt to assure the requested QoS; nevertheless, it will not provide any guarantee [9]. Real-time applications mostly have adequate adaptability to actual packet delays and are tolerant of occasional delay bound violations; consequently, they do not necessitate a hard reliable bound. Therefore, real-time applications should utilize the MBAC advantages for their benefit.

It was reported in [8] that in a basic structure, a MBAC consists of three components: (1) admission decision algorithm; (2) traffic estimator; (3) resource estimator as shown in figure 2.8 [8]. MBAC extracts its decision based on the collaboration of these three basic components. Each one of these components has its specific function. The admission algorithm obtains frequent measurements from the system such as the estimated available resources and the ongoing traffic information. Basically, the traffic estimator is responsible to provide the admission algorithm with the needed information about the ongoing traffic such as its characterizations and capacity. On the other hand, the resource estimator updates the admission algorithm with the remaining recourses in the system. Upon the arrival of a new request, the admission decision algorithm is operated to take a decision regarding the admission of the new request. The admission decision algorithm uses the inputs from the traffic and the recourse estimator as well as it uses some information from the requesting flow such as its quality of service requirement and its traffic description.

As it reported in [8] , different studies have been proposed in order to present an efficient traffic estimator, for example, Time Window, Exponential Averaging, Point Sample, Adaptive Sampling, and Kalman filter [45] [7] [46]. Also, many admission decision algorithms have been proposed. These MBAC algorithms include MS (Measured Sum [7]), HB (Hoeffding Bounds [47]), TP (Tangent at Peak [48]), MC (Measure CAC [49]) and TE (Traffic Envelope [50]).

The main goal of MBAC algorithms is to maintain service guarantees to all calls while maintaining acceptable levels of network utilization. This goal poses challenges in heterogeneous traffic environments. Many of these challenges have not been addressed in literature and they were reported in [8] such as relaxing some of the restrictive assumptions, addressing the failure of existing MBAC algorithms to satisfy their QoS goals, providing accurate estimations of the traffic and remaining resources in the system, and considering more realistic network environments.

In this thesis, we will present a MBAC algorithm with M-LWDF scheduler. Particularly, MBAC is designed to be deployed in wireless MAN (IEEE 802.16) to support real-time traffic. The M-LWDF scheme is effectively designed to support real-time traffic in wireless networks in term of the packet delay. M-LWDF maintains the delay of each traffic flow below a predefined threshold value; moreover, it takes the instantaneous channel quality experienced by the user into account. The proposed scheme is to enhance M-LWDF functionality in terms of QoS. In particular, our MBAC is to ensure that the feasibility of QoS provisioning by M-LWDF scheduling scheme is held. Basically, new calls requests will be denied if packet delays experienced by the existing users are close to the delay deadline.

2.10 Summary

In this chapter several issues about CAC in wireless networks has been discussed. Fundamental aspects about CAC has been briefly presented such as the purpose of CAC algorithms, major challenges in designing CAC, and basic components of CAC and its classifications. Surveys of important traditional CAC schemes were investigated. Several CAC approaches pertaining to IEEE 802.16 for providing QoS guarantees to real-time multimedia applications have been discussed. The significance of using MBAC to support real-time applications in IEEE 802.16 has been illustrated. Finally, the main contribution of this thesis is summarized.

Chapter 3

Measurement-based Admission Control

In this chapter, MBAC algorithm, for real time traffic in IEEE 802.16, is proposed. Our MBAC algorithm attempts to fulfill and improve the performance of delay-sensitive applications such as Voice over Internet Protocol (VOIP), Internet Protocol Television (IPTV) and video conferences. These applications are very vital in our life. Therefore, designing an algorithm to improve their efficiency is very important.

A crucial requirement of any network claiming to support real-time applications is to schedule all packets with some form of bounded delay. In order to maintain this bound, limiting the number of users entering the system by using an admission control algorithm is necessitated.

With the intention of achieving the above objective, many algorithms have been proposed in literature. For instance, in [51], traditional real-time service provides a hard bound on the delay of every packet [7] in which admission control algorithm uses worst-case analytical bounds as its basis [8]. Because of the bursty nature of network traffic, these types of admission control schemes normally suffer from low network utilization. MBAC; however, can achieve potentially better network utilization [8]. Real-time applications are delay and loss sensitive, yet they can bear some loss and delay; therefore, they are tolerant of occasional QoS violations. Consequently, efficiency in achieving high network utilization can be granted by using the MBAC. MBAC uses actual traffic load measurements and QoS performance to make admission control decisions in which a new call will be rejected if there is no available bandwidth to accommodate it; otherwise, accepting the new call will violate the QoS of the existing calls. MBAC provides a good network utilization and predicted QoS where the network will attempt to assure the requested QoS; nevertheless, it will not provide any guarantee [9]. Real-time applications mostly have adequate adaptability to actual packet delays and are tolerant of occasional delay bound violations; consequently, they do not necessitate a hard reliable bound. Therefore, real-time applications should utilize the MBAC advantages for their benefit.

The previous aspect of utilizing MBAC advantages is the focus of this thesis. We will combine MBAC with M-LWDF scheduling scheme in which the objective of the admission control scheme is to ensure that the feasibility of QoS provisioning is held. The M-LWDF scheme is effectively designed to support real-time traffic in wireless networks in term of the packet delay. M-LWDF maintains the delay of each traffic flow below a predefined threshold value; moreover, it takes the instantaneous channel quality experienced by the user into account. In our MBAC, basically, new call requests will be denied if packet delays experienced by the existing users are close to the deadline.

In this chapter, we will present an overview of M-LWDF scheme, advocated in [10] for wireless networks. Following the overview, we will present a MBAC algorithm with M-LWDF scheduler to be implemented. Particularly, MBAC is designed to be deployed in wireless MAN (IEEE 802.16) to support real-time traffic. The proposed scheme is presented to enhance M-LWDF functionality in terms of QoS.

3.1 M-LWDF Scheduling Algorithm

M-LWDF, proposed in [10], is a scheduling algorithm which supports QoS of multiple real-time applications sharing a wireless link. By considering the problem of multi-user variable channel scheduling, the algorithm tries to satisfy delay constraints of all users. Concerning the mentioned problem, it is very important to induce large and fast channel fluctuations, so variations of channel quality can be used to maximize the channel capacity. M-LWDF takes advantage of the difference in channel quality by prioritizing users with better channels.

As indicated in [10], M-LWDF provides two different types of QoS in terms of delay and throughput. To support real-time flows, packet delays must not exceed a certain value, $Pr\{W_i > T_i\} \leq \xi_i$, where W_i is a packet delay for this user, and parameters T_i and ξ_i are the delay threshold and the maximum probability of exceeding it, respectively. Another form of QoS is to satisfy that the average throughput R_i provided to user i need to be equal or greater than some specified value r_i, $R_i \geq r_i$.

Assume there are S users in a system, and each user receives a flow of data. In order to provide the delay requirement for all users, all queues must be kept stable. The M-LWDF discipline basically chooses the user i for transmission at time t with the maximum value of $\gamma_i W_i(t) r_i(t)$, where $W_i(t)$ is the head-of-the-line (HOL) packet delay for queue i, $r_i(t)$ is the channel capacity with respect to flow i, and γ_i is arbitrary positive constant which can be different for each user. The delay requirement can be met by setting an suitable value of γ_i (see figure 3.1 [10]).

The M-LWDF scheme is very straightforward. The scheduler can be implemented by using the time stamp of arriving data packets of all users, or the current queue length. Scheduling decision relies on both current channel conditions and the states of the queues. Besides, packet delay distributions for different users can be controlled by setting an appropriate choice of parameters γ_i. Thus, minimizing packet delays for flow i can be done, at the cost of a delay increase for other flows, by increasing the parameter γ_i for that user, while keeping γ_j s of other users unchanged. Even though M-LWDF can deal with all flows, it does not assure delay requirement for all users. As a results, choosing a suitable selection of of the parameters γ_i is very important. It was reported in [52] that M-LWDF scheduling, with $\gamma_i = a_i/\overline{r_i}$, $a_i = -(log\delta_i)/T_i$, and

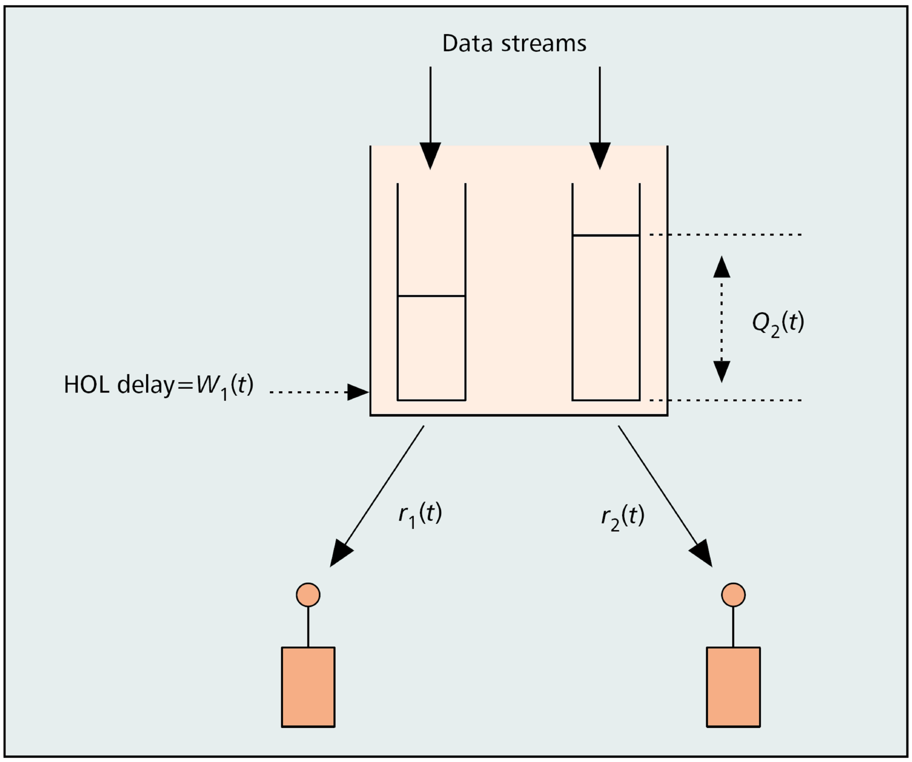

Figure 3.1: M-LWDF scheduler

$\overline{r_i}$ being the average channel rate with regard to to user i, functions effectively.

Parameter ai represents the QoS requirement. For instance, two users have the same delay thresholds, but the desired maximum violation probability i is less for the second user than for the first user; therefore, the second user is serviced with higher priority over the first user. Regarding the former parameters, the M-LWDF schedular selects a user with the maximal value of $a_i W_i(r_i(t)/\overline{r_i})$ to be scheduled.

As mentioned previously, the MLWDF scheduling provides assured QoS if it is feasible at all. To ensure that the feasibility of QoS provisioning is held, presenting an efficient CAC is necessitated, which is the focus of this thesis. Basically, new calls requests will be denied if packet delays experienced by the existing users are close to the delay deadline.

3.2 MBAC for Real-time Traffic in Wireless Network

The main objective of this thesis is to design an admission control algorithm with M-LWDF scheduling scheme in order to enhance M-LWDF functionality in terms of QoS. Therefore, the performance of our proposed admission control has been studied mainly under the M-LWDF scheduling discipline. In our system, we assume that we have N users, and each user receives a flow of data. Our scheme can be implemented for any

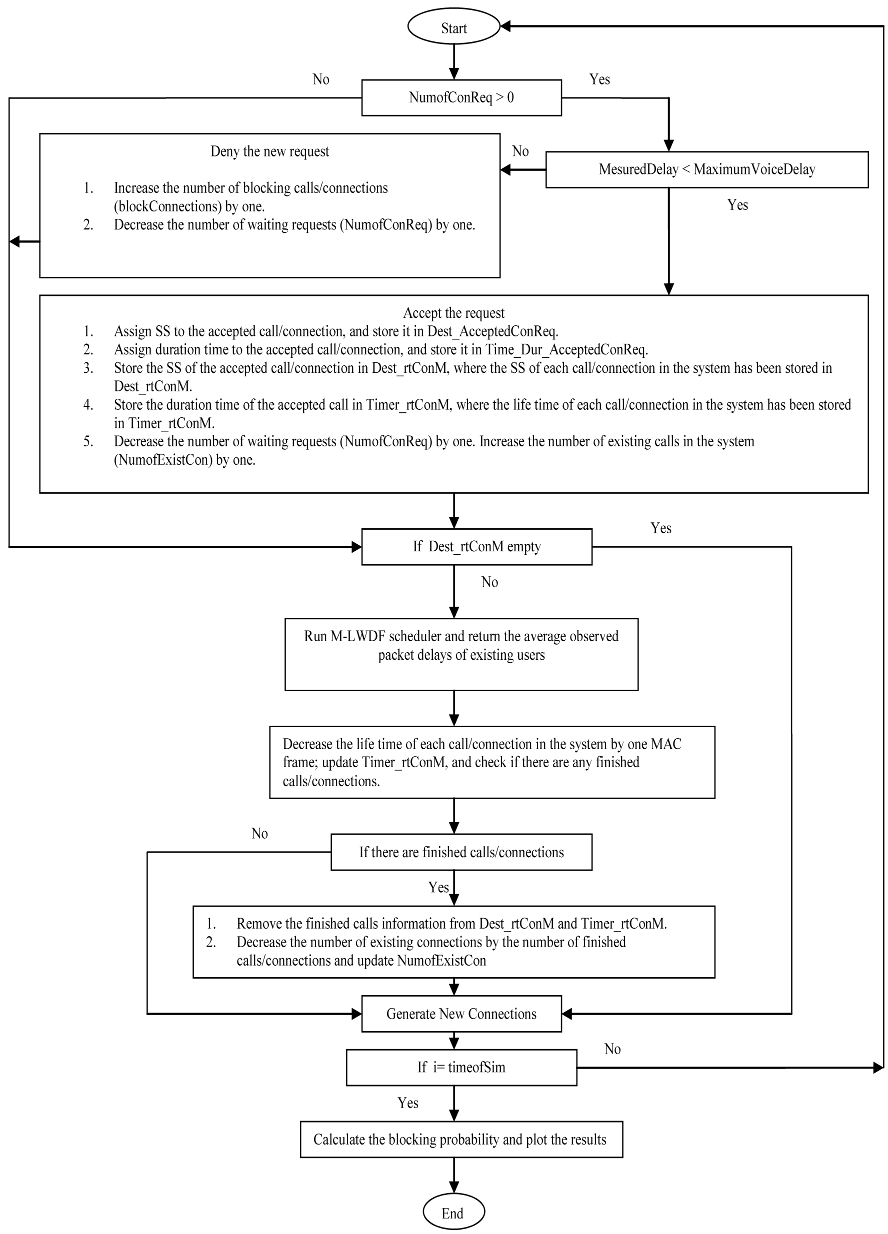

Figure 3.2: CAC algorithm for real-time traffic

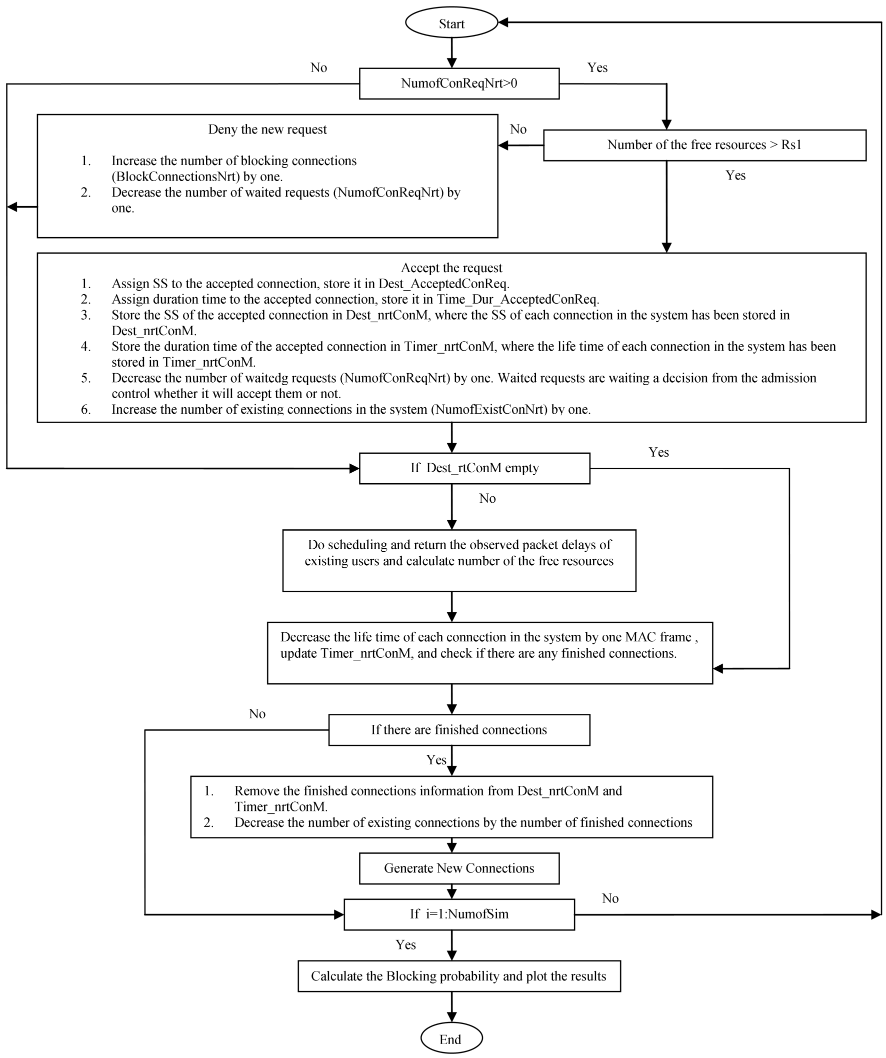

Figure 3.3: CAC algorithm for non real-time traffic

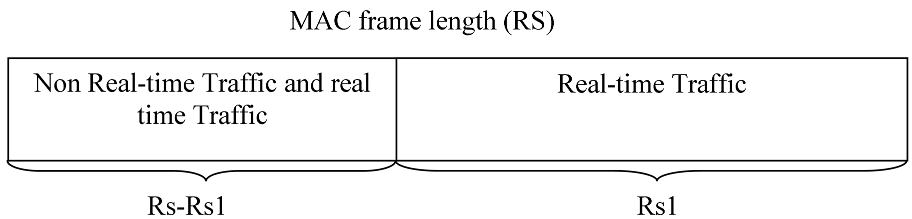

Figure 3.4: MAC frame partitioning

type of traffic. In IEEE 802.16 scenario, we will consider real-time and non real-time traffic such as voice and FTP respectively. We will adopt M-LWDF scheme in the system and measure the experienced average packet delay for existing real-time users. The delay measurement is used in our CAC algorithm, which is described in figure 3.2. It can be seen that upon the arrival of a new request, the admission control algorithm rejects the request if admitting the new call could violate the delay bound of existing calls; if the request satisfies all inequalities in figure 3.2, the new call is accepted.

Real-time calls should be serviced with higher priority than non-real time connections. Therefore, we use a reservation-based method to provide a lower call block probability for real-time service, where a fixed portion of the resources is exclusively reserved for real-time calls. As shown in Figure 3.4, an MAC frame is partitioned into two parts. The portion Rs1 is exclusively reserved for real-time calls, while the rest, which is less than Rs1,is shared by both non-real time connections and real-time calls. Therefore, call admission control operates as the following (see figure 3.2 and 3.3). If the number of the free resources is less than or equal to Rs1, only real time requests can be accepted and all non real-time requests are blocked. Admission control policy is demonstrated in Algorithm 1.

Algorithm 1 Admission Control Algorithm

if $NumofConReq > 0$ **then**

  if $(MeasuredDelay < MaximumVoiceDelay)$ **then**

    Accept the request
    $NumofConReq = NumofConReq - 1;$
    $NumofExistCon = NumofExistCon + 1;$

  else

    Deny the request
    $NumofConReq = NumofConReq - 1;$
    $Blockconnections = Blockconnections + 1;$

  end if

end if

if $NumofConReqnrt > 0$ **then**

  if (number of the free resources $> Rs1$) **then**

    Accept the request
    $NumofConReqnrt = NumofConReqnrt - 1;$
    $NumofExistCon_nrt = NumofExistConnrt + 1;$

  else

    Deny the request
    $NumofConReqnrt = NumofConReqnrt - 1;$
    $Blockconnectionsnrt = Blockconnectionsnrt + 1;$

  end if

end if

Execute the M-LWDF Scheduler **Return** MeasuredDelay and number of the free resources.

We declare the following:

- $NumofConReq$ is the number of waiting real-time requests.
- $MeasuredDelay$ is the observed average packet delay of existing real-time users.
- $MaximumVoiceDelay$ is the delay bound.
- $NumofExistCon$ is the number of existing calls in the system.
- $BlockConnections$ is the number of blocking calls in the system .
- $NumofConReqNrt$ is the number of waiting non real-time requests.
- $NumofExistConNrt$ is the number of existing non real-time connections in the system.
- $BlockConnectionsNrt$ is the number of blocking non real-time conections in the system .

3.3 Simulation Results

To support our claim of providing efficient MBAC, we focus on delay requirement in our admission control. Accordingly, we are interested in maintaining packet delay with acceptable call blocking probability. The quest for efficiency among different traffic classes while giving real-time traffic higher priority than non real-time traffic has been courting extensive efforts. Therefore, extensive simulations are conducted with MATLAB to evaluate and demonstrate the performance of the proposed MBAC scheme in terms of packet delay and call blocking probability.

In the simulation, we consider an IEEE 802.16 network in PMP mode, which is composed of a BS and 20 SSs. At the MAC layer, time is divided into MAC frames with the fixed length of 10 ms. A MAC frame is composed of downlink subframe (DL subframe) followed by uplink subframe (UL subframe) with equal length.

We consider voice and FTP traffic in our simulation. For real-time traffic, The call holding time is exponentially distributed with mean of one minute. The maximum average packet delay (packet delay threshold) is 150 ms, which is considered as an acceptable voice delay as indicated in [53]. The other simulation parameters are listed in table 3.1.

At the beginning of each MAC frame, the call admission control algorithm makes a decision to admit or deny the request of a new call. Each call has its QoS requirement in terms of maximum packet delay. A call will be rejected if the average packet delay of existing users exceeds a threshold. The call holding time is exponentially distributed with mean of one minute. We adopt the M-LWDF scheduling scheme in the simulation to allocate the resources to the admitted calls.

We assume an IEEE 802.16 Wireless MAN-OFDM operating at unlicensed band (5 GHz). Rayleigh distribution has been considered to characterize the fading channel of non-line-of-sight transmission paths. Rayleigh distribution is a statistical probabil-

Simulation Parameters	
Parameter	Value
BS power budget	20 Watt
System bandwidth	$5MHz$
Queue size	10^6 bits
Voice packet size	$66 * 8$ bits
preamble	2 OFDM symbol
FCH	1 OFDM symbol
TTG	2 OFDM symbol
MPDU header	6 byte
MPDU CRC	4 byte
DL-MAP	$9 + 4 * n$ byte
n	Number of transmitted bursts in each DL subframe
OFDM symbol duration	13.891μ sec
Rs1	6 ms
Rs-Rs1	4 ms

Table 3.1: Simulation Parameters

ity density function that represents the envelope of two Gaussian-distributed variants in quadrature [54], i.e., the Rayleigh distribution can be attained mathematically as the limit envelope of the sum of two quadrature Gaussian signals [55]. In our channel model, Rayleigh distribution describes the distribution of the channel gain. The amplitude of channel gain that is perturbed by Rayleigh fading is exponentially distributed. The average gain of channel span is in the range of 5 to 25 dB. The channels are equally numbered and have average gain of channels of 5, 10, 15, 20, and 25. Values of channels gain at each subframe are generated with an exponential distribution. At the time of generation, the best modulation and coding rate for the corresponding channels are selected from table 3.2. Each burst is transmitted with the best rate except for the preamble and FCH that are sent by BPSK.

Modulation and coding schemes of the IEEE 802.16			
Modulation	Coding rate	Channel gain(db)	Data rate(MBPS)
BPSK	1/2	6.4	6.91
QPSK	1/2	9.4	13.82
QPSK	3/4	11.2	20.74
16QAM	1/2	16.4	27.65
16QAM	3/4	18.2	41.47
64QAM	2/3	22.7	55.30
64QAM	3/4	24.4	62.21

Table 3.2: Modulation and coding schemes of the IEEE 802.16

The performance of MBAC in term of packet delay and call blocking probability is given as follows.

3.3.1 Packet Delay

Our admission control scheme decides to accept or reject a new call based on the measured average delay of exiting calls in the network. The scheduler operates to allocate the resources to the admitted calls. Measured delay is obtained from the scheduler. The measured delay must be less than the threshold of maximum average packet delay to accept a new request. Otherwise the call will be denied.

Figure 3.5 shows packet delay versus arrival rate of calls. Note that the packet delay increases as the number of accepted calls increases. At low system load (arrival rate of calls $<$ 8 calls/ms), the packet delay is low while the delay increases rapidly

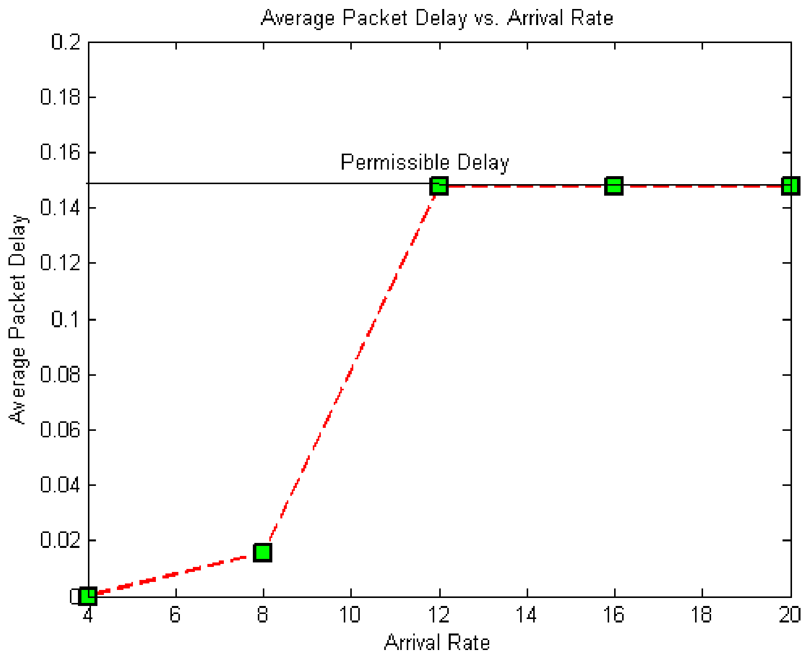

Figure 3.5: Average packet delays vs. arrival rate

at medium system load (arrival rate of calls is equal or greater than 8 calls/ms and less than 12 calls/ms). In the heavy load case (arrival rate of calls $\geq$ 12 calls/ms), the packet delay increases sharply; consequently, the CAC scheme attempt to maintain the delay requirement by blocking new calls.

3.3.2 Call Blocking Probability

Figure 3.6 depicts the call blocking probability with different arrival rates of calls. Note that the call blocking probability for real time traffic is zero at low and medium system load (arrival rate of calls $<$ 12 calls/ms), which indicates that no new call has been blocked and the existing calls enjoy their requested service. However, in the heavy load case (arrival rate of calls $\geq$ 12 calls/ms), the packet delay increases sharply in a way that accepting a new call may violate the network promises in term of the delay requirement. Consequently, CAC scheme attempts to maintain QoS by blocking new calls.

For non real-time traffic, the call blocking probability is zero at low system load, which indicates that no new request is blocked and the existing connections enjoy their requested service. However, in the medium and heavy load case, CAC scheme starts to block non-real time requests to maintain the promised QoS for all the admitted users.

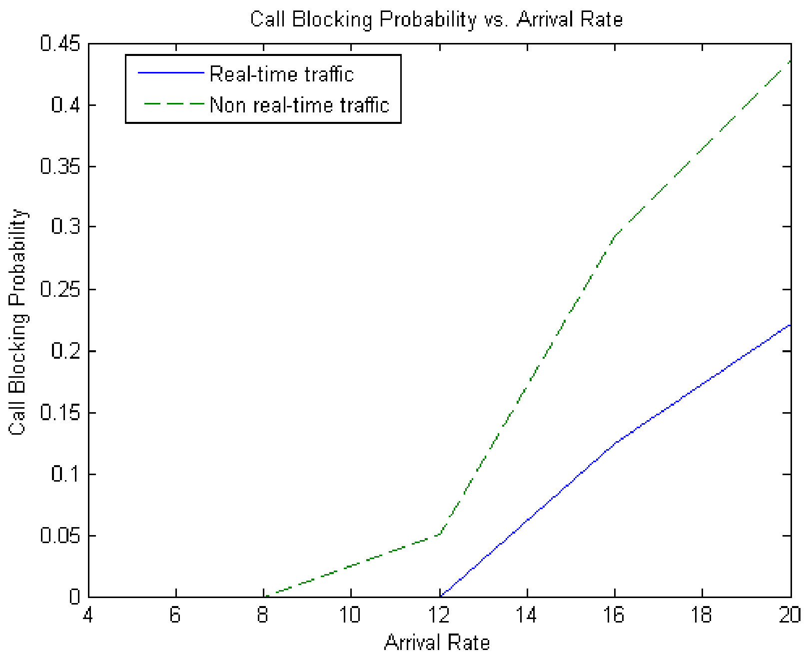

Figure 3.6: Call blocking probability vs. arrival rate

Chapter 4

Conclusion and Future Work

To support real-time applications, in this thesis we have presented an efficient MBAC for M-LWDF scheduling scheme to be deployed in wireless network. The objective of the admission control scheme is to admit new calls into the system without jeopardizing the maximum packet delay bound. Measured values of the average packet delay from the system have been used in the admission control algorithm. As long as a new flow can obtain the requested service and the packet delay of the existing flows are not risked by admitting it, the new flow will be accepted into the system. Simulation results show that the algorithm maintains good packet delay performance.

4.1 Future Directions

With future developments, our CAC algorithm has means of expanding to the following:

- Considering heterogeneous traffic in the system

- Providing different forms of QoS
- Considering mobility and handoff events
- Designing Parameter-based Admission Control and compare it with our MBAC to show that our MBAC can achieve potentially higher network utilization

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