Scheduling and Call Admission Control

A WiMax Mesh Networks View

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Abstract This chapter discusses the problem of providing Call Admission Control (CAC), scheduling and band reservation for wireless networks. It presents the importance of such procedures focusing mainly on WiMax mesh mode networks. The chapter also classifies some of the most known proposals presented in the literature to solve the scheduling and CAC problems for this kind of network. Differently of some other standards, in the IEEE 802.16 standard the scheduling and CAC procedures are mandatory. No node in the network can communicate, even in the mesh mode, without having the transmission previously scheduled. In this way scheduling becomes one of the most important processes to achieve spectral efficiency and, in consequence, to increase the network capacity.

Introduction

In the last years Wireless Mesh Networks (WMN) have been attracting a huge amount of attention from both, academia and industry. Indeed, WMN is now emerging as a promising technology for broadband wireless access [1, 2]. One of the main reasons for this sudden popularity of WMN is their inclusion in many of the IEEE wireless standards and in special the IEEE 802.16 [3]. The addition of the mesh mode to the IEEE 802.16 standard brought a series of advantages for these networks. Among them we can cite non-Line-of-Sight (NLOS) capacity, higher network reliability, scaling, throughput and availability [4].

However, to become really useful and valuable for the applications running on top of them, the WMN must to provide some level of Quality of Service (QoS). To fulfill this requirement, mainly for WMN environments, Radio Resource Management (RRM) techniques play a major role [5]. RRM is the term used to identify a series of strategies and algorithms employed to optimize the use of the radio spectrum and wireless networks limited resources. RRM techniques include frequency and/or time channel allocation, transmission power, access to base stations, handover criteria, modulation schemes, error coding schemes [6]. On behalf of [5] RRM policies, along with the network planning and air interface design, in deep, determine the QoS network performance at both individual user and network level.

This chapter focuses on the problem of providing Call Admission Control (CAC), scheduling and band reservation for the mesh mode of IEEE 802.16 networks [3, 11] also known as WiMax networks. Although these mechanisms are mandatory for IEEE 802.16 networks, the standard just specifies the signaling protocols and messages structure. The transmission scheduling control algorithm is left undefined. This makes the standard open to accommodate extensions and improvements. However, this also may lead, in the future, to incompatibilities among vendors' proprietary solutions.

For future readings, among many other works related to this one, we may highlight the survey presented by Kuran and Tugcu [7] in general emerging broadband wireless technologies. For a survey in general mesh networks the Alkydiz et al. work [1] presents a good overview on many aspects of the mesh networks, discussing how these aspects affect the entire network stack. The problem of CAC mechanisms in general is discussed in [5]. A broad view of the problem of distributed medium access control for mesh networks can be found in [8]. Zhao presents consistent view of the problem of distributed coordination in mesh networks in [9]. For a deep discussion, more specifically for 802.16 mesh networks centralized scheduling algorithms, see [10]. In [20] Redana and Lott present an analysis of the overhead caused by the control messages on the IEEE 802.16 mesh mode and show that, for multihop networks, the centralized approach have a better performance than the distributed one. For an analysis of the times involving the phases of the distributed scheduler mode see [21] and [22].

The remaining of this chapter is organized as follows: next section explains better what is CAC and scheduling. After that, the section WiMax Mesh Mode Overview presents an overview of the CAC and scheduling process for WiMax mesh mode networks. Section Taxonomy presents a possible classification for CAC and scheduling proposals and classifies some of the most well known proposals of the literature in accordance to the proposed taxonomy. Sections Ideas to Consider and Open Issues, presents, respectively, some of the most interesting techniques of the previously classified approaches and some possible directions for future researches on the field.

Background

This section presents a deeper discussion of what is CAC and scheduling, showing the importance of such mechanisms for the performance of networks in general and, in special, for the WiMax mesh mode.

As shown in the Fig. 1, the call admission control procedure is responsible for granting/denying access to the network. The decision of which connections are accepted and which one are not, is based on predefined criteria, taking into account the network status and the requirements of new calls. The admitted calls are then controlled by other mechanisms of the RRM, such as the schedule. The schedule is the RRM process that decides which one is the best moment to grant bandwidth for the admitted calls.

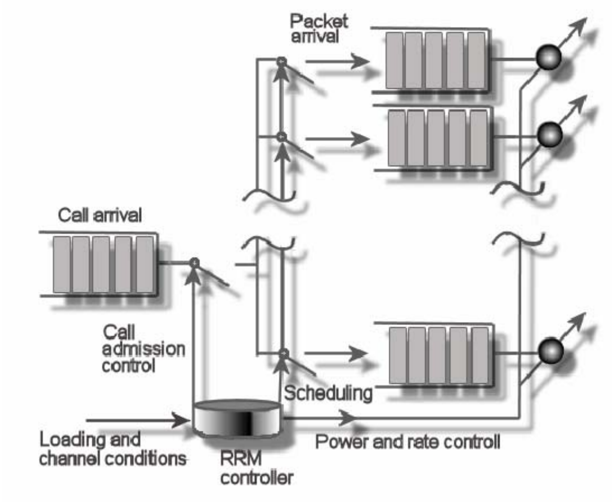

Fig. 1 - The radio resource management model [5].

Just considering only throughput, ignoring any other QoS parameter, the scheduling problem is proven to be an NP-hard problem for multihop wireless networks [12, 13]. This means that if the number of nodes, or links, in the WMN increases it becomes computationally impossible to find the optimal scheduling solution. So, in this context, suboptimal scheduling solutions, with lower complexity, are acceptable and even desired for mesh environments.

CAC and scheduling play a central role in the WiMax networks and it is not only because they are mandatory, their importance is far beyond that. They indeed provide a number of important features to the network. Among such features we can highlight: network signal quality, call blocking, dropping probabilities, control of packet delay and transmission rate guarantee. CAC and scheduling mechanisms have been extensively studied for both wired and wireless networks. However, because the intrinsic characteristics of the medium, the application of these techniques for wireless environments is much more challenging than for wired ones.

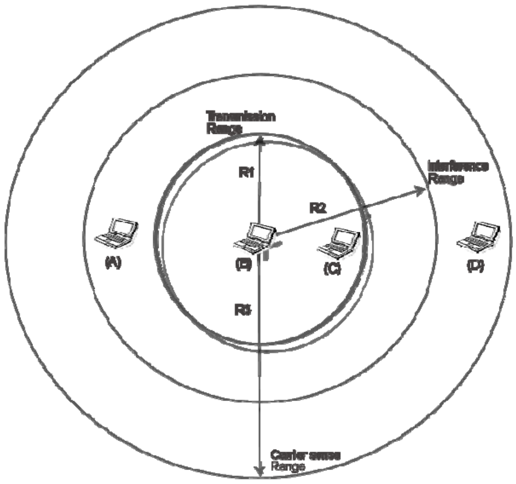

Fig. 2 - Different ranges in the nodes communication**.**

We need to remember that, by principle, the wireless medium is a broadcast one where, at any time, a number of different stations are addressing the channel concurrently. The main problem with this is that, if concurrent transmissions occur in the same carrier frequency at the same time, this may result in mutual destruction of the transmitted signals. Unfortunately the interference range is greater than the transmission one. The receiver can only decode or sense the message if the Signal-to-Interference-and-Noise-Ratio (SINR) is above some level. For example, in the Fig. 2, node D can have its signal jammed by the signal sent from B to C and may not be able to actually decode the signal. The interference range means that any transmission made from A, which is in the interference range, can damage the signal between B and C. These different ranges can lead to a number of different scenarios, among them the hidden and exposed node problems, common in IEEE 802.11 networks. For WiMax networks, scheduling and CAC are the techniques used to avoid the interference problems. However, regardless the claims that WiMax networks are free from such problems, Zhu and Lu [14] show they can also occur in WiMax environments.

Reasons to use CAC and scheduling

Among the main reasons to use CAC and scheduling schemes we have guarantee of the signal quality, guarantee of transmission rates, decreasing in call dropping probability, possibility to observe packet level parameters, maximization of revenues, prioritization of services and fairness in the medium access.

- *Signal Quality*: CAC schemes guarantee the signal quality once they ensure that a new connection will only be accepted if the network can afford it. The scheduling intends to organize the nodes and decrease the network interference.
- *Transmission Rate*: CAC schemes ensure that the network can offer, at least, the minimum rate required by a given communication and the scheduling observes that the promised transmission rate is really achieved.
- *Call Dropping Probability*: Dropping an ongoing call is normally much more troublesome, from the user point of view, than blocking or delaying a new call. In this way CAC mechanisms are normally used as a control switch to limit new calls in favor of ongoing calls or handoffs.
- *Packet-Level Parameters*: CAC schemes can be used to evaluate if a new call will damage the network performance observing packet-level QoS parameters, e.g. packet delay, delay jitter and throughput. The scheduling may also use such information to improve the quality of the connection.
- *Revenue-Based CAC*: Each new call in the network may bring some kind of revenue to the network. CAC schemes may be used to evaluate such benefits and costs for new connections and decide which calls are more interesting to accept and keep.
- *Prioritize Some Services/Classes*: Some classes of services may have priority over others. CAC schemes can, for example, be used to give priority for traffics that represent better revenues for the network operators. The schedule can also beneficiate such traffics in the resources allocation in detriment of others.
- *Fair Resource Sharing*: Even seeming contradictory, regarding the two previous items, the fairness exists if it is based in some predefined parameters and observed among traffics in the same classes and between different classes.

Aspects to observe

There are some aspects that good CAC and scheduling schemes should observe. Among the most important ones we have: channel utilization, fairness, end-to-end delay, throughput and QoS support.

- *Channel Utilization*: The greater the channel utilization the better, once it represents the fraction of time used to transmit user data packets in a given period.
- *Fairness*: Traffic flows, with the same QoS level, should gain equal chances to use the wireless medium. However, mainly in highly loaded situations, internal scheduling polices may lead to unfairness. This, as a network behavior, is normally undesirable and should be avoided as much as possible.
- *End-to-end delay*: This aspect refers to the elapsed time between the generation

of a packet at the source station and the correct reception of the packet at the final destination station. The delay performance relays on protocol capabilities of avoiding collision and exploiting spatial reuse. It relays also on the protocol efficiency of channel access and achieved fairness.

- *Throughput*: Throughput is the volume of user data transferred between two stations in a given period. Throughput is one of the most widely used performance metrics. The schedule and CAC algorithms are considered better than others if they help to increase the throughput.
- *QoS support*: CAC and scheduling schemes are considered as part of the MAC layer protocols. However, they should be able to understand and consider the QoS preferences of the upper layers flows, guaranteeing their specific requirements, such as throughput, packet loss ratio (PLR), packet delay and jitter requirements.

Scheduling types of services

The IEEE 802.16 standard defines five different scheduling types of services: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Extended Real-time Polling Service (ertPS), Non-real-time Polling Service (nrtPS), and Best Effort (BE). Table 1 summarizes the main characteristics of these five types of services.

Characteristic / Scheduling type	Max Sustained Traffic Rate	Min Reserved Traffic Rate	Max Latency	Tolered Jitter	Traffic Priority	Request/ Transmission Policy	Piggy Back Request	Bandwidth Stealing
UGS	M	O	M	M	X	M	NA	NA
rtPS	M	M	M	O	M	M	A	A
ertPS	M	M	M	M	M	M	A	NA
nrtPS	M	M	X	X	M	M	A	A
BE	M	X	X	X	M	M	A	A

M - Mandatory O – Optional X - Not Available A – Alowed NA – Not Alowed

Table 1 - Services and their main parameters and characteristics**.**

- *Unsolicited Grant Service – UGS*: Designed to support real time data streams where packets are generated in a fixed data rate. For example, VoIP connections without silence suppression. The mandatory QoS parameters for this service are Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter, Uplink Grant Scheduling Type and Request/Transmission Policy. Once the rate is constant, if present, the Minimum Reserved Traffic Rate parameter should has the same value as the Maximum Sustained Traffic Rate parameter, once the data rate is constant. The grants for this service are issued periodically and without any explicit request. The main advantage of this is that it eliminates the overhead and the latency of the SS (subscriber station) issuing for new grants for this specific traffic.

- *Real-time Polling Service – rtPS*: The Real-time Polling Service is designed to support the same kind of traffic that UGS does, but with variable data rate, e.g. MPEG video. The mandatory QoS parameters are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Maximum Latency, Uplink Grant Scheduling Type and Request/Transmission Policy. Differently of the UGS flow, this service offers periodic unicast request opportunities for the SS to adjust the size of its grants.
- *Extended Real-time Polling Service – ertPS*: The extended rtPS service, introduced latter into the standard [11], is a service based on both UGS and rtPS. For ertPS the flow has some amount of resource reserved in an unsolicited grant way, but the allocation may change if the SS requests for that. In other words, the allocation is dynamic and depends on the needs of the SS, but when set it works as the UGS type. The key service information elements are the Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Maximum Latency and Request/Transmission Policy. The extended rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as Voice over IP services with silence suppression.
- *Non-real-time Polling Service – nrtPS*: The nrtPS is designed to support delay-tolerant data streams consisting of variable-sized data packets that require variable data grant on regular basis. FTP (File Transfer Protocol) is an example of application that could use this kind of service. The mandatory QoS parameters for this scheduling service are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Traffic Priority, Uplink Grant Scheduling Type and Request/Transmission Policy. The advantage of this kind of service is that it can support data streams even in very saturated network conditions. The mesh BS (Base Station) provides SS the opportunity to request bandwidth using unicast and contention period. In addition, piggyback request opportunities are also available.
- *Best Effort Service – BE*: Best Effort service intend to be used for any other kind of traffic that does not have any significant QoS requirements and that can be handled on a space-available basis, e.g. http and e-mail traffic. The mandatory QoS service flow parameters for this scheduling service are Maximum Sustained Traffic Rate, Traffic Priority and Request/Transmission Policy.

WiMax Mesh Mode Overview

The WiMax mesh mode, introduced in the standard by the IEEE 802.16a amendment [15], supports two different physical layers: WirelessMAN-OFDM™, operating in a licensed band, and WirelessHUMAN™, operating in an unlicensed band. Both of them use 256 point FFT OFDM TDMA/TDM for channel access and operate in a frequency band below 11GHz.

Even though the standard permits both Time Division Duplex (TDD) and Frequency Division Duplexing (FDD) as access scheme, for the mesh mode only the TDD is allowed [3]. This means that the uplink and downlink transmissions share the same frequencies and, doing so, they must to occur at different times. However, for IEEE 802.16j, the relay networks upcoming part of the standard some people proposed the use of FDD on it [16].

The Mesh frame is divided into control and data sub-frames. There are two types of control sub-frames: schedule control and network control sub-frame. The network control sub-frame provides basic functionality for network entry and topology management. The schedule control sub-frame controls the transmissions. The scheduling is done negotiating minislots ranges for the traffic demands of each link. All the communications are done in terms of the links established between nodes. All data transmissions between two nodes are done through one link and the QoS is provisioned over links on a message by message basis. Upper layer protocols are in charge of the traffic classification and flow regulation.

Message Type	Name	Description	Connection Mode
39	MSH-NCFG	Mesh Network Configuration	Broadcast
40	MSH-NENT	Mesh Network Entry	Basic
41	MSH-DSCH	Mesh Network Distributed Schedule	Broadcast
42	MSH-CSCH	Mesh Network Centralized Schedule	Broadcast
43	MSH-CSCF	Mesh Network Centralized Schedule Configuration	Broadcast

Table 2 - Mesh MAC Management Messages**.**

Scheduling policies

In Mesh mode all transmissions must to be scheduled, not even the Mesh BS can transmit without having its transmission coordinated with other nodes [3]. To organize the medium access, the standard defines three different schedule mechanisms: coordinated centralized scheduling, coordinated distributed scheduling and uncoordinated distributed scheduling. These three schedule policies can be either used alone or together in the same network.

According some authors the centralized schedule should be used for external traffic and the distributed schedule for intra network traffic [17, 18]. This came from the fact that the centralized schedule trusts in a mesh BS, which is in last instance, a backhaul responsible for act as gateway between the internal and external network traffic. Table 2 presents the messages used by the CAC and schedule mechanisms in the WiMax mesh mode.

Centralized scheduling

For the Centralized Scheduling, the mesh BS schedules all network transmissions, even the mesh BS ones. The resource request and the mesh BS assignments are both transmitted during the control portion of the frame. The centralized scheduling coordinates the transmissions and ensures that they are all collision-free. Once the BS has the knowledge of the entire network, it is typically more optimal using the spectrum than the distributed forms. Algorithm 1 [19] defines the downstream transmission ordering for MSH-CSCF, or MSH-CSCH, messages, being the upstream transmission ordering the same, but in the reverse order.

```
// Downstream MSH-CSCF or MSH-CSCH messages use the following algorithm
Begin {
        The mesh BS initiates the frame;
        Collect the eligible children of the mesh BS, with hop count equal 1;
        Order them in by their appearance in the most recent MSH-CSCF packet;
        Transmit in accordance to the established order;
        If (The message does not fit entirely in a subframe)
            Fragment the message;
        While (Exists eligible nodes) {
            Increase the hop count by one;
            Ordered nodes by their appearance in the MSH-CSCF packet;
            Transmit in accordance to the established order;
            If (The message does not fit entirely in a subframe)
                Fragment the message;
        } // while
        If (A node's order requires it to transmit immediately after receiving)
                Insert a MinCSForwardingDelay delay;
} // Begin
```

Algorithm 1 - Centralized scheduling control transmit order algorithm [19]**.**

The MSH-CSCH message has two variants, MSH-CSCH Request and MSH-CSCH grant. With the MSH-CSCH Request each node estimates and reports the level of its own upstream and downstream traffic demand to its parent. This demand comprises also the demands reported by the node's children. With the MSH-CSCH Grant the mesh BS propagates down, through the routing tree, the levels of flows and grants to each node in the network. Fig. 3 shows an example of message flow for the centralized schedule.

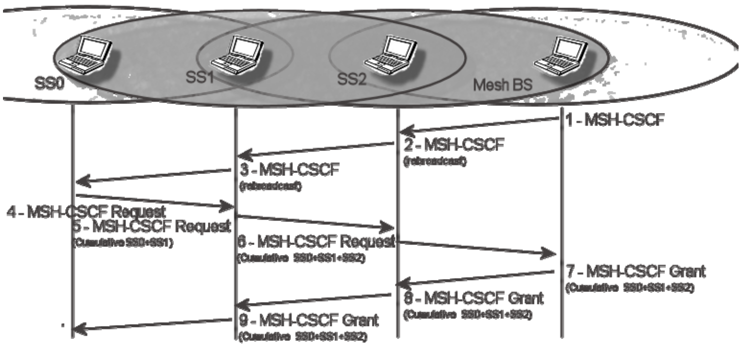

Fig. 3 - A message flow example for the centralized scheme**.**

All MSH-CSCH Grant messages contain information about all network grants, since all nodes need the complete information for the schedule computation. Upon receiving any message in the current scheduling sequence and assuming that nodes have up-to-date scheduling configuration information, any node is able to compute locally the schedule for all transmissions, including its own. Besides the mesh BS, a node should not transmit any downstream centralized scheduling packet without receiving a MSH-CSCH message from a parent. Also, a node should not send any centralized scheduling packets, if its MSH-CSCF information is outdated.

In terms of eligibility to send and receive MSH-CSCH messages, all nodes are eligible to retransmit the grant schedule, except those with no children. For transmitting MSH-CSCH grant messages, all nodes with children are eligible. For transmitting MSH-CSCH request messages, all nodes, except the mesh BS are eligible.

Distributed scheduling

In both distributed scheduling mechanisms, coordinated and uncoordinated, all the stations in the two hop neighborhood must to have their transmissions coordinated to avoid collision. The coordinated distributed scheduling uses the control part of the frame to transmit its own traffic schedule. Both schedule schemas, centralized and distributed, may coexist at the same time at the same network.

The uncoordinated distributed scheduling is a simpler version of the distributed scheduler and may be used for fast ad-hoc setup of schedules in a hop-by-hop basis. The uncoordinated schedule is basically an agreement between two nodes and should not cause collision with the data and control traffic scheduled by the coordinated schedules. Both coordinated and uncoordinated distributed scheduling employ a three-way handshake to setup the connection.

The first message in the three-way handshake is a MSH-DSCH request. The transmission is scheduled using a random-access algorithm among the “idle” slots of the current schedule. If the attempt was unsuccessful a random backoff is used to avoid new collisions. Fig. 4 shows schematically the messages in the distributed schedule three way handshake.

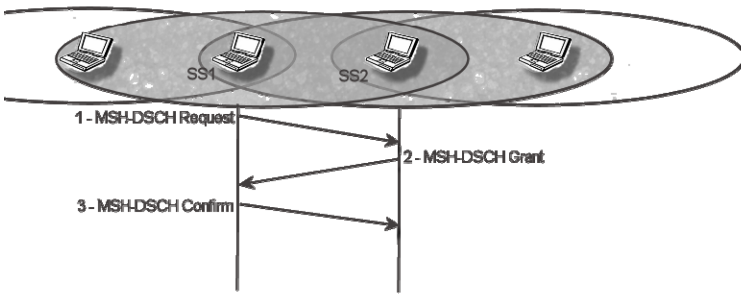

Fig. 4 - Distributed Scheduling Three Way Hand Shake**.**

The MSH-DSCH Grant can be issued by any neighbor that listens the MSH-DSCH Request. The grant message contains the list with the subset of the resources awarded. The first granter node may start its grant transmission in the immediately following base-channel idle minislot. More than one granter may also respond the request.

The requester node sends the same received MSH-DSCH Grant message in confirmation. Doing this the requester's neighbors became aware of the grant awarded. The grant confirmation is then sent in the first available minislots following the minislots reserved for the grant opportunity of the last potential granter.

Network configuration

Two more messages, responsible for create and maintain the network configuration, may be transmitted in the network control sub frame: Mesh Network Configuration (MSH-NCFG) and Mesh Network Entry (MSH-NENT).

A new node that wishes to join the mesh network needs to wait until listen a MSH-NCFG message. When the new node receives this message it is able to establish the synchronization with the mesh network. In truth it should decide which node will be the best sponsor for its communication, so the new node may wait for more than one MSH-NCFG message to arrive. When the sponsor node is chosen, the new node sends though the sponsor a MSH-NENT message to the mesh BS with its registration information. The sponsor node then establishes a quick schedule, through the uncoordinated scheduler process, and communicates it to the new node. The new node confirms the schedule and sends the required security information. Finally, in the last step, the sponsor node grants the new node access to the network.

Taxonomy

This section presents a possible classification for the proposed algorithms for CAC and scheduling for IEEE 802.16 networks and also frames some of the most important works of the literature on this classification. Fig. 5 shows a diagram with the topics used in the classification and Table 3 presents how some important works fits on the classification. The aspects observed are: operation mode, design level, channel awareness, spectrum reuse, type of traffic and QoS observed.

As Fig. 5 shows, one proposal can, and indeed should, present more than one of the observed characteristics. It is perfectly possible to have, for example, a proposal that has a centralized approach, with cross layer design, that try to maximize the number of active links and that observe QoS parameters. Actually this is exactly the case of the proposal presented in [23]. However it is important to highlight that the topics presented here are, by no means, an extensive list, in special in what concerns the QoS support aspects. The values present in the classification are just some of the more common used to distinguish the algorithms. Other classifications can be found in [8] and [5].

- *Operation mode*: The operation mode reflects if the proposal focuses in the centralized or distributed mode of the standard. In the centralized approach all the scheduling and CAC decisions are made in the mesh BS. Without a central coordination, distributed approaches are more challenging than centralized ones. All the communications in the IEEE 802.16 networks must to be synchronized. It is important to notice that the synchronization problem is considerably harder in a distributed environment. Both schedules can be running simultaneously inside the network, using different messages and configuration slots. Although this is a standard and expected organization for slots, even explicit in the standard [3], the work of Cheng et al.[8] shows that the avoidance of such division may lead to better performance results.
- *Design Level*: The conventional protocol stack requires different protocol layers to be transparent to each other. This normally leads to simpler and more scalable implementation and operation for protocols. Unfortunately, this design approach does not necessarily lead to an optimum solution for wireless networks [1]. The CAC and the scheduling mechanisms are normally agreed to be

part of the protocols from the MAC layer. However, some proposals have interfaces to receive information from other network layers and such information may influence the protocol behavior, in the MAC layer. Because the unreliability and relative vulnerability of the wireless links the crosslayer approach may lead to better results.

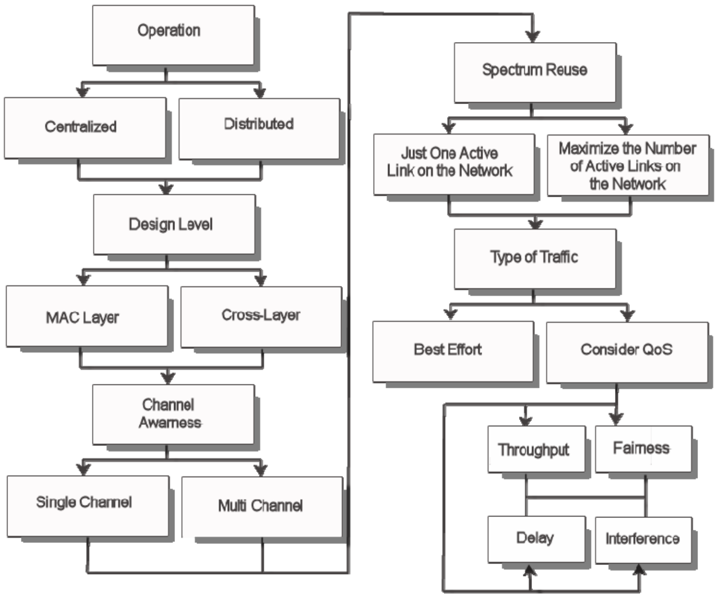

Fig. 5 - Proposed classification for WiMax mesh mode CAC algorithms**.**

- *Channel Awareness*: The channel awareness aspect is related to how the proposal treats and perceives the communication channel. Some approaches treat every communication as occurring in one single communication channel, others allow the communication to be divided into different frequencies. The use of multi-channel communication allows more than one communication to occur at the same time, into different frequencies, even among neighbor nodes. The OFDM technology, used in the WiMax mesh mode, permits nodes to transmit different messages into different sub-carriers. This makes the scheduling problem more interesting and effective in avoiding collisions and increasing the network capacity. However, the allocation of frequencies makes the scheduling problem even harder. Other point to observe is that to use multi-frequency the scheduled channels must to be orthogonal to avoid interference. Considering that, one must be aware that part of the available frequency spectrum is lost.
- *Spectrum Reuse*: Some protocols permit, even incentive, the spectrum reuse as a mean to increase the spectral efficiency. On the other hand, consider possible just one transmission in the whole network at a time, even though the standard

permits spectrum reuse.

- *Type of Traffic*: Some protocols make distinction between the kinds of the traffic they are handling, while others do not. The differentiation normally targets the possible QoS traffics presented in the section *Scheduling services*.
- *QoS Aspects Observed*: Some scheduling and CAC mechanisms observe QoS aspects to enhance and improve the network behavior. The QoS aspect observed may be in terms of the quality of the flows, e.g. throughput and delay, or may be in terms of fairness of access medium for the calls. We also consider the use of other techniques, such as interference minimization, also as a QoS aspect. Again, a proposal may present more than just one of these aspects.

Proposal	**Operation Mode**	**Design Level**	**Channel Aware**	**Spectrum Reuse**	**Type of Traffic Considered**	**QoS Aspects Observed**
[20]	Distributed	MAC	No	No	No	No
[25]	Centralized	MAC	No	Yes	Yes	5 types of service
[26]	Distributed	MAC	No	No	Yes	Priority channels
[27]	Distributed	MAC	No	Yes	Yes	Yes
[28]	Centralized	MAC	No	Yes	Yes	Yes
[18]	Dist/Central	MAC	No	Yes/No	No	No
[29]	Centralized	MAC	No	Yes	No	No
[30]	Centralized	CrossLayer	No	No	No	No
[31]	Centralized	MAC	No	Yes	No	No
[32]	Centralized	CrossLayer	Yes	Yes	Different rewards for dif. connections	QoS and Non QoS connections
[33]	Centralized	CrossLayer	No	No	Yes UDP and TCP	Yes
[34]	Centralized	CrossLayer	No	No	No	Yes
[35]	Centralized	CrossLayer	No	Yes	No	Yes
[36]	Centralized	MAC	No	Yes	Yes	Yes, all the classes
[17]	Centralized	CrossLayer	No	Yes	Yes TCP and UDP	No
[23]	Centralized	CrossLayer	No	Yes	No	No
[48]	Distributed	MAC	Possible	Yes	No	No

Table 3 - Main proposed method Classification**.**

Table 3 presents some of the most known proposals for CAC and scheduling for IEEE 802.16 networks classified in accordance to the proposed taxonomy.

Comparison of some of the main existing proposals

Each one of the existent proposals has its own objectives and mechanisms, therefore any comparison among the strategies is, in principle, unfair. Some of the works just want to test one aspect of the IEEE 802.16 Mesh mode CAC and scheduling problem, while others try to go further and really implement the mechanisms in the terms the standard proposes. Without implementing all proposals and comparing them within the same parameters and conditions it is unlikely that any one can affirm, without any shadow of doubt, which one is the best. Indeed, some works, like [24] that implemented some different proposals, have consistent results comparing the performance of the implemented ones. However, here our purpose is to present a summary of the most relevant ideas to guide future works on this field. The comparison, summarized in Table 3, is done in architectural terms and based on the taxonomy purposed on the beginning of the section. This comparison does not intend to show which proposal is the best or even the most complete one. In our opinion it is more interesting here to observe the proposals and try to evaluate how to use all the different techniques they present to improve the network performance.

Thoughts for Practitioners

As stated previously, no communication is allowed in WiMax networks, if not previously scheduled. This means that, more than correct and well designed, the CAC and scheduling mechanisms must also be fast and computational efficient enough to process all the network traffic. In addition to this, the scheduling problem in multihop networks is proven to be NP-hard [12, 13]. Because this, some optimal techniques normally present also an alternative heuristic, not optimal, to solve the problem [27, 32, 34]. In the real world, sub-optimal solutions may be the only way to apply scheduling and CAC techniques to mesh networks.

The fairness is another interesting issue and, probably, one of the most diverse aspects among the proposed methods. The fairness is in truth an umbrella that accommodates many different definitions. However, it is commonly agreed that some kind of fairness is valuable for the network [37]. A peculiar, although interesting fairness approach, dynamic fairness, is introduced in [17]. The concept of dynamic fairness seems to be more interesting for the link unstable mesh network context, even though in the general case neither hard nor dynamic fairness is welcomed. Other simple and efficient ideas related to fairness, like the establishment of threshold for different class of services presented in [26, 36, 38], can also be interesting and even applicable in conjunction to other different techniques.

Many of the proposed approaches also proved that the interference is a real problem that must be treated carefully. The proposals to handle the interference vary in many senses and can use, for example, a conflict graph [27] or a conflict matrix [29]. For TDMA like approaches the techniques can be the constructing better routes [31, 34, 35, 23] or dividing the spectrum [32].

Mainly for the centralized scheduling, it is agreed by many of the proposals that the creation of a scheduling tree is the best approach [17, 25, 27, 30, 31, 32, 33, 35, 23]. If we consider the OSI seven layers model [39], the creation of this tree rooted at the mesh BS is routing and, in truth, part of the job of the network layer. In this sense such proposals present a crosslayer design. Such kind of proposal normally presents really good perspectives and seems to be a good direction for new proposals to follow.

The standard itself [3, 11] defines a series of different types of services, presented here in section *Scheduling Services*, to be used by the applications. These services are considered by some approaches [8, 25] in conjunction to their particular characteristics. Some of the approaches, more than just consider differentiation between the different services, also consider during the scheduling and CAC a reward for connections [32] or nodes [29] served. One of the main objectives of the CAC and scheduler in these approaches is to maximize the reward of the network. It is important to notice here that this really may provide better quality to the nodes in the privileged classes, but can be very unfair to other classes. We need to keep in mind that the available amount of resources is always the same. Sometimes to present gains some techniques may penalize some users. This must be done really carefully to avoid rash unfairness.

The standard states that the grants, even for centralized approaches, should be done hop by hop. Normally the approaches distribute the grants exactly in this way, but some proposals go little beyond that. In [25], for example, it is proposed that each node should be represented by n different virtual nodes, being n the number of different services. This intends to make easier the manipulation of the scheduling and the grants distribution among the services and nodes.

Directions for Future Research

The WiMax mesh mode is a good and valuable approach, but it is still a young part of the IEEE 802.16 standard and presents a lot of room for improvements. In this section we will discuss some topics that, in the best of our knowledge, were not explored deeply enough yet for this kind of networks.

A number of parameters must to be set to reach good protocol performance e.g. holdoff exponent, periodicity of MSH-NCFG messages. Some consistent work has been done analyzing the network performance, but more works exploring these parameters are needed and surely enough would represent a valuable contribution to the field. The holdoff exponent value, for example, strongly affects IEEE 802.16 performance [4] and not many works have explored this.

The characterization of the traffic distribution on the mesh network is also important, not only for network simulation purposes, but also to be used in the design of newer and better algorithms. Some authors, when analyzing and validating their protocols just use poison or normal distribution to generate traffic. Also in [40] is argued that wide-area network traffic is much better modeled using self-similar processes [41]. However, for wireless mesh networks, the traffic distribution and patterns for the different QoS services is still to be studied, at least in deeper way.

Some works present good results working with orthogonal channel allocation for IEEE 802.11 mesh networks [42]. This kind of technique could be even easier applied in WiMax networks, but, again, little has been done exploring this field. The frequency reuse is another topic that may be important for Mesh networks, and that has been studied for PMP (Point to Multi Point) WiMax networks [43], but not for the mesh mode.

A new working group is studying the problem of relay networks, the IEEE 802.16j, that is a problem very near to the mesh networks one. In the best of our knowledge, up to now no schedule or CAC mechanisms were proposed to such networks. Apart from that, could also be interesting to study the mix of both networks, IEEE 802.16 mesh mode and IEEE 802.16j, for example, adding some relay points in the mesh network [40]. This can open new opportunities for scheduling and routing, where new algorithms can take advantage of the relay characteristics to help the network performance.

So far, in the best of our knowledge, no work on CAC or scheduling for WiMax mesh mode makes use of Adaptive Power Allocation (APA) to decrease the interference in the network. Much more in opposite, some techniques even consider always node at full power transmission [33]. Some work on this field, using APA and CAC mechanisms have been studied for PMP networks [44, 47], but no work addressed it for WiMax mesh networks.

Mixing networks, many different standards address mesh as a valid architectural topology e.g. IEEE 802.16, IEEE 802.20, but so far no work addressed the interconnection of such standards. Some people explore hierarchical approaches for CAC for CDMA networks [45]. The general idea could be also applied to IEEE 802.16 mesh mode, as well the cluster based reservation, explored in [46].

We observe also that no technique so far considers mobility, even though mobility being a key aspect for wireless mesh networks. Indeed, there are no guarantees of how the actual methods will behave in face of mobility. New and efficient procedures must be designed to handle handoffs and the constant position changing in the network topology.

Some techniques approach the scheduling and CAC problems using simple heuristics. However, could be interesting to see how to apply more sophisticated artificial intelligence techniques to solve the scheduling problem, once it is a NP-hard one.

Some techniques propose some schema of reward for connections, which can be used as indicative of revenue, but up to now no one discussed about the billing in such networks. No one likes to talk about it, but who and how one will pay for the access for WiMax networks and how this will influence the CAC mechanism is not fully comprehended yet. Cheng et al. present in [8] a list of open research issues on CAC mechanisms for wireless networks in general, and truth also valid for mesh networks. A good discussion about important emerging trends and future research issues for CAC mechanisms can also be found in [5].

Conclusion

This chapter presented an overview of the CAC and scheduling schemes for IEEE 802.16 mesh mode standard. The literature presents many CAC and scheduling algorithms for many different kinds of networks, including WiMesh networks. Some of these algorithms are even suited to very specific networks and situations. However, for the general case, the broader and fairer the algorithm the better it is considered, once normally one hopes to use the same algorithm in a broad range of situations.

The IEEE 802.16 is still a young standard and CAC and scheduling mechanisms for it are not fixed yet. As this part of the standard is open for different implementations this represents an opportunity for research. Comparisons of different schemes and the proposition of innovative algorithms are always welcomed by those who work on this field.

Terminologies and Keywords

- **CAC – Call Admission Control**: Comprehends the mechanisms to decide if a new call is accepted or not.
- **Scheduling**: The decision of when the previously accepted calls will have their share of resources.
- **RRM – Radio Resource Management**: identify a series of strategies and algorithms employed to optimize the use of the radio spectrum and wireless networks limited resources. CAC and scheduling are examples of such strategies.
- **Wireless Mesh Networks**: Kind of wireless network without a fixed structure and where the nodes that provide access are also wireless nodes.
- **Mesh BS – Mesh Base Station**: Network node that has the responsibility of concentrate and organizes the network. Normally is a network backhaul.
- **Backhaul**: A node that has connections with both wireless and outside network.
- **IEEE 802.16**: IEEE standard that define the communication for broadband wireless networks.
- **WiMax - Worldwide Interoperability for Microwave Access**: An initiative to ensure the IEEE 802.16 compatibility and interoperability among different implementations and even promote compatibility with other broadband standards, mainly the HIPERMAN, the European standard.
- **QoS – Quality of Service**: Term used to identify the need for a differentiated kind of traffic from a call. CAC and Scheduling are examples of mechanisms used to ensure that the calls will maintain the desired/requested QoS level.
- **MAC – Medium Access Control**: part of the network stack, in the IEEE standards, that defines topology dependent access control protocols.

Questions

1. Explain what it is scheduling and its importance to Mesh networks.
   R.: Scheduling is the decision of when a previously accepted call will have its share of resources. It is important once it helps to improve the network capacity and fairness.
2. Discuss about three reasons to use CAC and scheduling algorithms.
   R.: As seen in the section *Background* among the reasons pointed to use CAC and scheduling algorithms we have *signal quality*, once CAC accepts new connections only if the network can afford it and the scheduling tend to decrease the interference over the network. *Transmission rate* is ensured by the CAC once new connections are only granted if there are enough resources to grant it. The scheduling is exactly the mechanism in charge to provide the required transmission rate. *Call dropping probability* is also observed once these schemes may prevent ongoing calls to be dropped in favor of new calls.
3. Comment three of the points to observe about CAC and scheduling algorithms
   R.: The section *Aspects to observe* raises some points that good CAC and scheduling algorithms should observe. *Channel Utilization* is the idea that one of the main concerns for the protocol should be increase the channel utilization. If we increase the amount of time the channel is used, we can share this resource among the nodes increasing their access to the network resources. *Fairness* is a good quality for CAC and scheduling mechanisms. It is easy to increase the channel utilization, for example, is only a mater of giving all the resources to one single node. This would increase the channel utilization but the other network users would not like that, and with reason. Fairness is, among others, grant access to every user in accordance to previously established rules. *End-to-end delay* is the time between the generation of a packet and its successful delivery at the destination. CAC mechanisms should be built with this guarantee in mind and new calls should be analyzed against this value. The scheduling mechanism also should observe it and work the best to keep this value as low as possible for the different kinds of traffic.
4. Explain, with your own words, each type of service defined in the IEEE 802.16 standard
   R.: See section *Scheduling types of services*
5. Consider a medical application that permits a doctor to perform an online non-presential surgery. Which type of service would be more suited for this kind of application and why?
   R.: Well I believe that if any one of us where the patient we would surely enough demand, no matter what, an UGS connection. Normally for real time critical applications the use of UGS is more suited, even more if you have

lives trusting on it.

6. It is possible for applications that use BE, as a connection type, to have more bandwidth than those that use other mechanisms?
   R.: Apart from the BE kind of traffic, the resources are requested between a range of values Max Sustained Traffic Rate and Min Reserved Traffic Rate. Normally the schemes work trying to provide the maximum resources as possible for the calls which some kind of QoS requirements. If the channel is over provisioned and all connections received the maximum requested resources, than the still available resource is divided among the BE connections. If the available resources are enough, so yes, it is possible that the BE connection to have more resource than the other scheduling types.
7. Get one of the algorithms of the Table 3, explain it, summarize its main advantages and disadvantages and check its classification in accordance to the taxonomy.
   R.: Fair and efficient multihop scheduling algorithm for IEEE 802.16 BWA systems [29].

   Main points:

   - Centralized scheduling
   - Fairness, equal bandwidth to every node
   - Spectrum/spatial reuse
   - No traffic differentiation
   - Collision matrix

   The centralized scheduling algorithm proposed by Kim and Ganz in [29] try to maximize the network throughput while try to reach fairness in terms of each nodes scheduled bandwidth. The proposal does not trust, or require, information about any other layer apart from the MAC layer. It is a perfect example of proposal designed to obey the layers scheme. The proposal is divided in two phases, the first called Node ordering and the second called Link allocation.

   The node ordering phase consists of ordering the nodes in accordance to their satisfaction index. The satisfaction index is defined as the ratio between the number of allocated bandwidth, during a preconfigured interval time, and the node's total weight. The node's weight is a factor that may be used to reflect the node class or priority and is set during the network initialization. The total weight is the sum of the node weight with the weight of all its child nodes, the nodes it provides access.

   In the second phase, the link allocation phase, receiving the MSH-CSCF message with the node ordering, each node determines the whole network transmission schedule. The method works with two matrices, a schedule matrix and a collision matrix. After inserting a node in the schedule matrix, all nodes in the extended neighborhood, nodes within 2 or 3 hops, are added to the collision matrix. To avoid collisions the authors present three rules: First, no node may transmit and receive data simultaneously. Second, no neighbor of a sending node may transmit data and third, no neighbor of a receiving node may transmit data.

Even simple the method reaches efficiency of 94.8%, when compared with the maximum possible throughput, being 5% the maximum fairness variance. Other conclusion of the work is that both phases are needed to reach a high throughput. The main concern about this work is the use of hard fairness. The node is scheduled even if it has no data to transmit. Cao et al. show in [4] that such fairness approach undermines the possible network capacity. The efficiency of the network of 94.8% is just possible if all nodes have demand for bandwidth and this demand is always nearly the same, what is unlikely to occur in real environments.

8. Propose a new scheduling algorithm that respects the IEEE 802.16 specification and classify it in the taxonomy.
   R.: There is no right or wrong answer, just propose a simple algorithm based on any one you have seen so far. A good idea is often base your algorithm in common daily situations. Analyze for example, how it is the CAC and schedule algorithms in a poker game, restaurant, or any other environment you familiar with.
9. Analyze your algorithm and evaluate its strong and weak points, verify for which kind of traffic and network it fits better.
   R.: This answer is dependent of the previous one and, again, there is no right or wrong answers. Just try to frame your proposal on the classification proposed in the section *Taxonomy*.
10. Why if you force all communications in the network to occur in a scheduled way do you tend to avoid problems such as hidden and exposed terminals?
   R.: The hidden and exposed terminal problems occur because no entity takes care of giving nodes permission to transmit in the network. Forcing every communication in the network to be scheduled forces the existence of an entity that grants these communications. This high level entity, that can be centralized or distributed, have a better knowledge of the network, once every one needs to ask it permission to transmit. In this way this entity is able to grant permission to nodes in a way that such problems are avoided.

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