Modelling Quality of Service in IEEE 802.16 Networks

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***Abstract*—While only relatively recently standardized, IEEE 802.16 or WiMAX networks are receiving a great deal of attention in both industry and research. This is so because with the increased emphasis on multimedia data, apart from the general advantage of wireless, 802.16 promises wider bandwidth and QoS as part of the standard. As a back haul network for other networks, in particular the 802.11a/b/g/e or WiFi networks, it is well suited. As for any new technology, there are many open questions of which Transmission Scheduling and Connection Admission Control (CAC) are the most prominent. The standard intentionally makes no statement about either function. Different from other performance models we have seen, we consider an analytical framework which takes into account the close relationship between the CAC algorithms and the Scheduler algorithms and is applicable to each mode of operation and admission control paradigm specified by the standard. The long term objective of this work is to present a hybrid analytic and simulation model, based on the proposed framework, for modelling QoS metrics in 802.16 networks.**

***Index Terms*—WiMAX, scheduling, call admission**

I. Introduction

While only relatively recently standardized, IEEE 802.16 or WiMAX networks are receiving a great deal of attention in both industry and research. A network consists of individual wireless cards, such as that shown in Figure 1 (taken from [1]) which act either as a Base Station (BS) or as a Subscriber Station (SS). Resource allocation is performed in the MAC under the control of the Driver.

The host interface communicates with the MAC controller and most of the time directly to memory using Direct Memory Access (DMA). That is, the host writes packets to a specific memory where the controller, using a particular scheduling algorithm, reads them and sends them. QoS in the MAC-based bandwidth reservation scheme or Scheduler of IEEE 802.16, cannot be decoupled from the QoS routing protocols, and play a significant role in the determining routing performance. With the Scheduler we understand not only the scheduling algorithm but also the buffer management required to ensure the QoS associated with a certain Traffic Class (TC) described below. The Scheduler is not involved in routing and call admission is done in the host. A cross-layer approach [2], [3] is needed

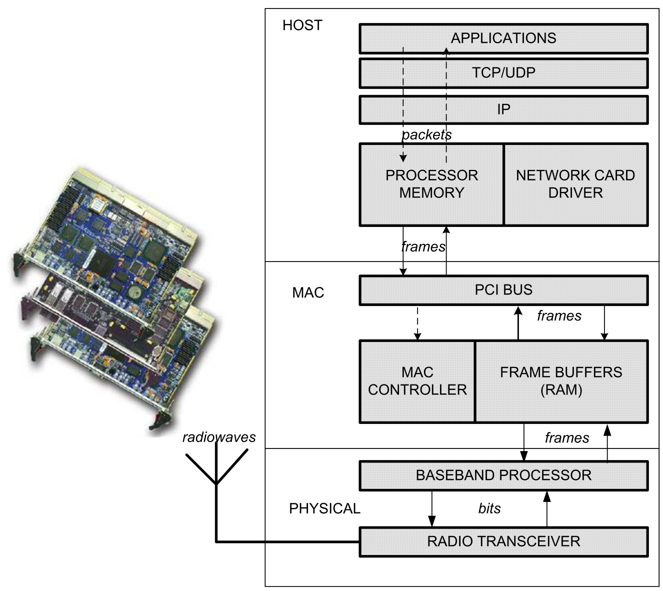

Fig. 1: Architecture of a Wireless Card

to make effective use of the MAC layer mechanisms when provisioning end-to-end QoS. Further work in this area is required to analyze the dependencies across layers and to find an optimal solution jointly across all protocol layers. This is the focus of this paper, in addition to analyzing sound algorithms to service the packet transmission queues to ensure that QoS requirements of applications are met as discussed, inter alia, by Wongthavarawat [4].

Though central to performance, IEEE 802.16-2004 standard [5] writers have purposely left the scheduling and Connection Admission Control (CAC) details out of the standard. Support for QoS, however, is a fundamental part of 802.16 Medium Access Control (MAC) layer design [6] where QoS is principally provided by the Scheduler and CAC. The fact that the 802.16 MAC is connection-oriented gives an 802.16 network the advantage of having greater control over network resources sharing amongst individual connections, making it possible to provide better QoS. The standard provides a basic

QoS platform to promote inter-operability between 802.16-based networks. Scheduling services are defined and should be supported by each 802.16 station for connection admission and transmission. These services are:

- *Unsolicited grant service* (*UGS*) that caters for real-time, fixed-size data packets with constant bit rate (CBR). This service is granted at regular time intervals without a request or polls.
- *Real-time polling service* (*rtPS*) that caters for real-time data packets that vary in size generated at periodic intervals, such as MPEG video and VoIP with silence suppression, where packet sizes are variable nature of the packet sizes.
- *Non-real-time Polling Service* (*nrtPS*), designed for connections that do not have delay requirements. *nrtPS* is similar to BE. It only differs from BE in that it guarantees a minimum BW. An example of *nrtPS* traffic is FTP.
- *Best-effort* (*BE*) that service makes no guarantee of service. To guarantee a minimum BW the connection must subscribe to the *nrtPS* service. An example of *BE* traffic is web browsing data.
- Extended real-time variable rate (*ertPS*), which was added in 802.16e-2005 (or Mobile-WiMAX), that supports real-time applications where the applications require guaranteed data rate and delay. This service is for applications that would typically, in 802.16-2004, subscribe to the *rtPS* service even though they may behave similarly to *UGS* traffic at times, such as VoIP with silence suppression.

The 802.16 standard describes either a Point-to-MultiPoint (PMP) or Mesh (MSH) mode. In Section II we discuss these modes and the different admission control paradigms. In Section III we explain the roles of, and the functional relationship between, the 802.16 Scheduler and CAC. The CAC and Scheduler play very different roles in that the former is closely related to routing and has to be located in the network layer. The Scheduler is a MAC function since it controls the up-link (UL) and down-link MAP (DL). Section IV presents the proposed Scheduler and CAC relationship framework and show that it can represent each of the possible modes of operation identified in Section II.

II. Operation and Admission Control

The 802.16 standard supports two basic topological modes of operation: A Point-to-MultiPoint (PMP) and Mesh (MSH) modes [7] of operation, shown in Figure 2. In PMP mode subscribers or Subscriber Stations (SS), communicate with the Base Station (BS) which acts as a central hub. The BS regulates up-link and down-link transmission between itself and its set of SSs, in a star topology.

The Mesh (MSH) mode of operation is moreover characterised by a multi-hop environment where every SS can communicate with every other SS as well as the BS. In this mode, 802.16 defines two mechanisms to schedule transmissions; either *centralized* or *distributed* scheduling [8]. In centralized scheduling the BS acts as a cluster-head, determining how SSs share the available time slots in an up-link radio frame.

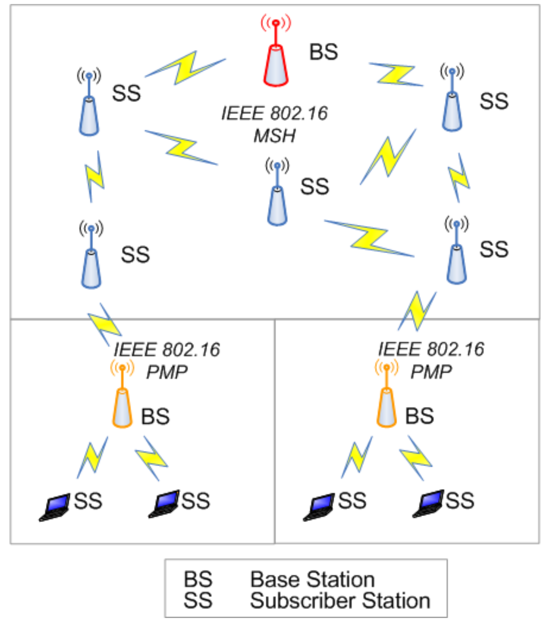

Fig. 2: Network Overview

This centrally coordinated approach to network management is much simpler than distributed scheduling where a number of BSs compete for channel access, called uncoordinated distributed MSH mode.

Even though CAC is not a MAC function, it is central to the QoS operation of 802.16 in either modes of operation. Apart from the modes, there are two admission control paradigms or traffic granting schemes defined in 802.16: Either Grant-Per-Connection (GPC) or Grant-Per-Subscriber-Station (GPSS). Under GPC, the CAC algorithm considers each individual connection arriving from an SS, while for GPSS each SS manages admission of its own individual connections before sending a single bandwidth (BW) request to the BS.

From what we have written so far it is clear that there are four combinations of operation and call admission, which we shall refer to as *admission control* (AC) modes in this paper. The combinations and our designation are:

- AC mode 1: PMP mode and GPC admission control
- AC mode 2: PMP mode and GPSS admission control
- AC mode 3: MSH mode and GPC admission control
- AC mode 4: MSH mode and GPSS admission control

III. Scheduling and CAC in 802.16

Performance models found in the literature [6], [9], [10] either consider the 802.16 Scheduler or CAC, but nowhere that we have seen do researchers distinguish adequately between the roles of either or identify the relationship between the two. While the Scheduler independently builds the DL-MAP and UL-MAP, the CAC needs to closely consult these in order to determine the available resources and consequently, whether to admit or deny a connection of a particular traffic type. Such information or control flow is often confused with the flow of data, perhaps because it is not clearly recognized that the two functions are located at different layers of the protocol stack.

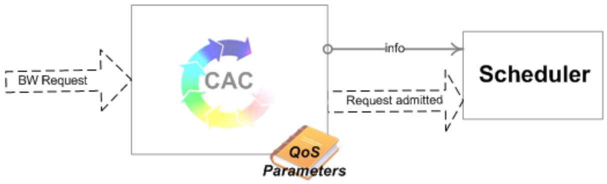

Fig. 3: Roles and Relationship between the 802.16 Scheduler and CAC from the CAC's perspective

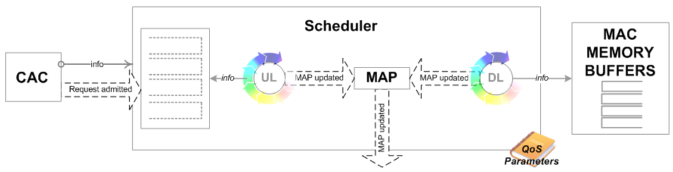

Fig. 4: Roles and Relationship between the 802.16 Scheduler and CAC from the Scheduler's perspective

In 802.16 the CAC decides whether a connection request is granted or whether a bandwidth (BW)-change is allowed. As seen in Figure 3, the CAC has as input either a Dynamic Service Addition (DSA; essentially a new connection), Dynamic Service Change (DSC) or a Dynamic Service Deletion (DSD). These need to be considered in terms of a set of predefined QoS parameters. It also needs to know the current resource state of the network which it can only determine by consulting the Scheduler. With that information, it applies the particular CAC algorithm and, as output in the figure, informs the scheduler of whether a request has been admitted or not.

The Scheduler shares the network resources amongst the connections that have previously been admitted. As seen in Figure 4, the Scheduler is responsible for both the UL-MAP, which decides the order of transmission from the SS to the BS, and the DL-MAP, which transmits data downward to the SS. Note that we do not explicitly consider data traffic destined for an Internet fixed-line network, since we assume that these will be sent from the BS on a high bandwidth fixed line which does not involve the Scheduler. Data arriving at the BS from the Internet environment, or new connection requests arriving from there, are treated as wireless traffic originating at an SS.

The Scheduler receives connection updates and schedules these requests in the UL-MAP by executing the UL algorithm that uses the virtual queueing information and the QoS parameters. The DL-MAP is updated by consulting the MAC Memory Buffers and executing the DL algorithm to decide the allocation of the down-link resource for these requests. Together the UL-MAP and DL-MAP are built by the Scheduler and they decide the MAP information used to coordinate transmission amongst the stations in the network. The Scheduler therefore has as output the updated MAP.

In the left-hand part of Figure 5, the protocol stack shows the data flow for up-link and down-link traffic arriving at and departing, respectively, from the 802.16 BS. On the right-hand side, the relationship between the Scheduler and CAC are shown as discussed above.

On the up-link information from the wireless medium enters the 802.16 Physical Layer (PHY), and the MAP maps

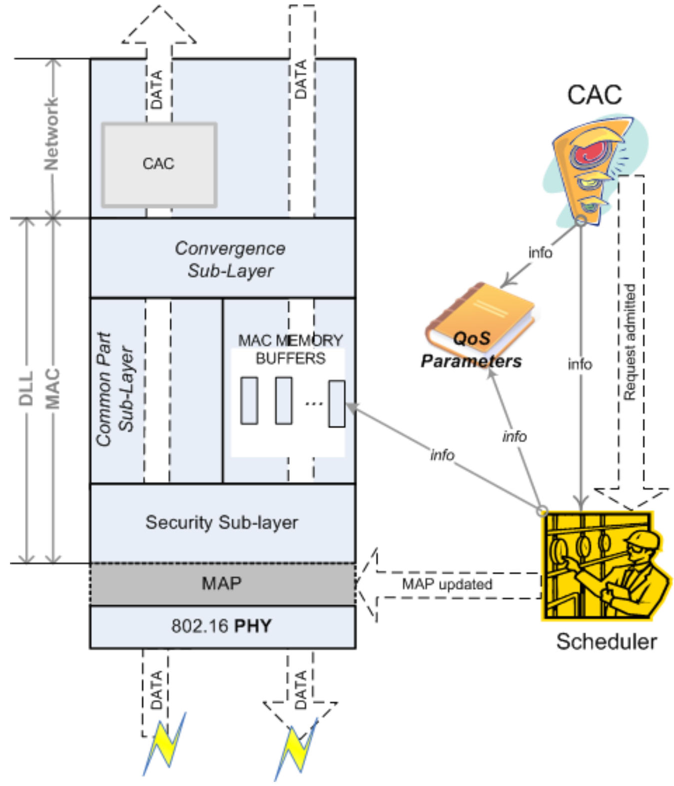

Fig. 5: Information flow between the 802.16 Scheduler and CAC and data flow.

incoming data or change requests with a particular connection as scheduled in the previous DL-MAP. This information enters the MAC layer, either being buffered there or not, depending on the implementation and then passes through the Security Sub-Layer, Common Part Sub-Layer (CPS) and the Convergence Sub-Layer (CS), in that order. The data or requests then enter the Network layer where the CAC would consider change requests as explained. Data, not destined for the BS, will be routed appropriately.

On the down-link, information that does not have as destination the BS, i.e. information that must be routed to another station, together with information generated by admitted connections of the BS itself, passes down into the MAC layer, through the CS, CPS and Security Sub-Layer. Information entering the CPS is queued in the MAC memory buffers. Information about these queues is, as mentioned before, used by the Scheduler to allocate or re-allocate resources. Information enters the PHY from the MAC memory buffers according to the DL-MAP and is transmitted over the wireless medium.

IV. Proposed Modelling Framework

Our proposed modelling framework is based upon individual models of the BS, in Figure 6, and the SS illustrated in Figure 7.

A. Base Station Model

Frames arriving at the BS were previously scheduled on the UL-MAP to be either BW requests or data PDUs to be

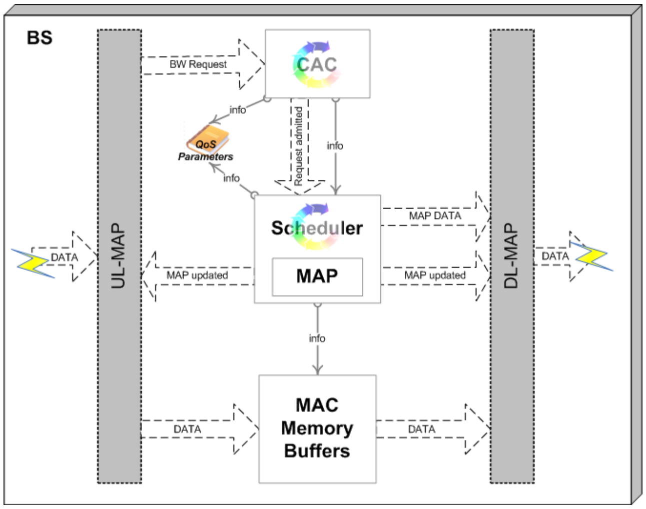

Fig. 6: Base Station Model

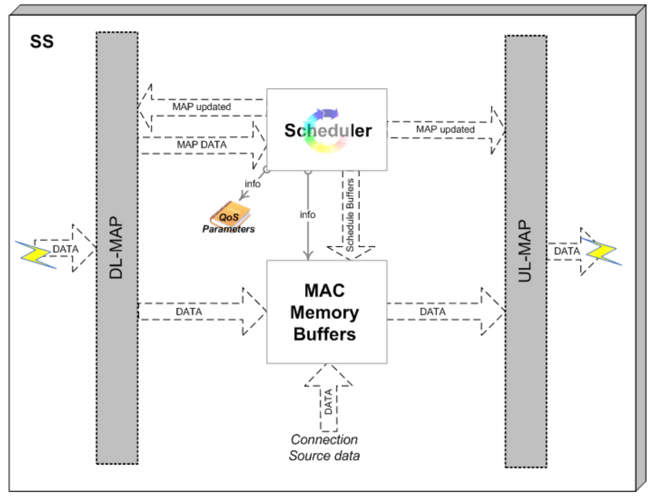

Fig. 7: Subscriber Station Model

forwarded on the DL or, less frequently, data PDUs destined for the BS itself (not indicated in the figure).

A BW request is taken up by the CAC that decides whether to admit the request and, if so, will pass this information to the Scheduler. Some authors, e.g., Cicconetti [6]*et al.* refer to "virtual queues", a designation we prefer not to use.

Information about these newly arrived connections or bandwidth change requests as well as buffer lengths, traffic types and so on of current connections are used by some scheduling algorithm to update the UL-MAP and DL-MAP for the next transmission. The UL-MAP essentially informs the schedulers at the SSs in the network of their turn to transmit on the uplink, assuming TDD, while the DL-MAP informs the SSs which data in the frame is destined for them.

B. Subscriber Station Model

The SS model is illustrated in Figure 7. Information arriving at the SS, as transmitted by the BS on the down-link according to the BS DL-MAP, are either updates for the SS UL-MAP, data PDUs to be routed through the SS, or data destined for the SS (not indicated in the figure).

The SS Scheduler has not been described in detail because it adheres to the MAP specified by the BS. However, in AC modes 2 and 4, the SS still adheres to the MAP schedule as dictated by the BS, but must also manage connection transmission schedules internally since, in those modes, the SS has been allocated resource for a group of connections. The SS therefore has an *SS UL Schedule* to manage these connections including the data to be routed. The SS MAC memory buffers are managed according to the UL-MAP and additionally by the SS scheduler in AC modes 2 and 4.

V. Model Framework Extension

The framework we have described are for the BS in PMP mode and with GPC admission control (AC mode 1). We shall perform analytic and simulation studies by use of a hybrid model where the Scheduler and the CAC are sub-models. These sub-models will be changeable, depending on various strategies involving the Scheduler and CAC algorithms and how the latter interoperates with the Scheduler and various scheduling services (UGS, rtPS, nrtPS, BE, ertPS).

Using QoS metrics such as BS utilization, bandwidth use, frame throughput, provider return throughput, call drop and call refusal probabilities, etc. we shall be able to predict the effect of each strategy.

A secondary objective would be to extend the model from GPC to GPSS admission control paradigm (i.e., AC mode 2), meaning that the SS Scheduler algorithm will be more complex but the SS model would not change. The BS model would remain the same and the GPSS call admission may imply less BW change requests.

Extending from AC mode 1 to 3, i.e. from PMP to MSH, means that the Scheduler and CAC at the BS will be far more complex and lead to worse performance at the BS. However, no structural changes need to be made to the BS model.

Extending from AC mode 2 to 4 can be done in the same way as was done for extending from AC mode 1 to 3. Therefore we believe the framework is suitable for developing performance models of 802.16 networks operating in any one of the four AC modes.

VI. Conclusion

In this paper we have focused on the dependencies across layers and the relationships between the Scheduler and CAC in 802.16 networks, and outlined BS and SS models to be used for analytic and simulation studies to investigate the effect of various strategies involving the Scheduler and CAC algorithms, and their effect on network productivity in terms of frame throughput, provider return throughput, bandwidth use and other performance indices.

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