QoS-Oriented MAC Protocols for Future Mobile Applications

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INTRODUCTION

Common intended access to a physically unshareable resource requires arbitration. Since in wireless communications the transmission medium cannot be shared without loss of information, *medium access control* (MAC) plays the role of an arbiter stipulating, for each of the intended users, the conditions and parameters of exclusive access rights. The major challenge in designing a good MAC protocol is to provide each user with the negotiated quality-of-service (QoS) parameters while, at the same time, utilizing the network resources as efficiently as possible. Thus, an ideal MAC protocol must strike a balance between the conflicting goals of QoS provisioning, efficiency, simplicity, and service controllability. The MAC protocol improvements ensure a dominant effect on the development of the QoS and other future breakthrough wireless technologies.

BACKGROUND

Future generation of global wireless and satellite multimedia communications for mobile multi-service applications requires dynamic (soft) control and stringent QoS guarantees. The MAC technology employed depends on the bandwidth allocation strategy, the scheduler algorithms used, and on the MAC protocol itself. As showed in Markhasin, Olariu, and Todorova (2004), QoS-oriented MAC technology, along with the all-IP/ATM architecture, is expected to provide cost-efficient broadband multi-service to mobile and geographically distributed users anytime and anywhere.

Assume that at some time t the system contains N_t mobile users belonging to k data priority service classes, with input multimedia traffic intensities G_{ikt}, output traffic intensities S_{ikt}, and total input intensity $G_t = \sum_{i,k} G_{ikt} \le C_{MAC}$, where C_{MAC} is the MAC protocol efficiency, and $C_{MAC} = \max_{\{G_t, t\}} \sum_{i,k} S_{ikt}(G_{ikt})$. A *QoS-oriented MAC* protocol must guarantee for each point in time t belonging to some interval $[t_1, t_2)$ the following required values:

a) QoS characteristics: average delay, loss probability, throughput;
b) traffic parameters: peak and average rates; and
c) bandwidth: the amount of bandwidth necessary to support the negotiated QoS.

Perhaps the most natural and straightforward arbitration strategies used in MAC is token based. Specifically, an artifact known as the *token* regulates access to the transmission medium. The arbiter allocates the token to users according to a scheduling strategy. The user that possesses the token has access to the resource; once the token is relinquished, the access right to the resource is lost. Many multimedia applications require effective control of the *token requests generation rate* variation, including token bank fair queuing (TBFQ) proposed in Wong, Zhu, and Leung (2003), recurrent M-sequences RS-token broadcast reservation (TBR-RS) proposed by Markhasin (1996), and also scheduler algorithm *priority parameters* regulation, local queue *buffer size*, and *ARQ quantity* of automatic request for repeat adjusting, as also shown in Markhasin (1996).

One can define static (*hard) QoS provisioning* as a session with static control parameters satisfying predetermined traffic profiles G_{ikt} = *const*(t). Bandwidth resource Y_{it} = *const*(t), ...$t \in [t_1, t_2)$ and other control parameters are regulated at long-term intervals only. Therefore hard QoS out-of-profile traffic is not guaranteed, so that performance degradation is possible (Wong et al., 2003).

Similarly, one can define *soft QoS provisioning* as a session with dynamic controlled/adapted QoS characteristics according to traffic profiles variation $G_{ikt} = \text{var}(t)$. Bandwidth resource $Y_{it} = \text{var}(t)$, $\ldots t \in [t_1, t_2)$ and other control parameters are regulated at short-term intervals (Markhasin, 1988).

According to Fattah and Leung (2002) and Wong et al. (2003), existing scheduler algorithms can be classified as *work-conserving* with non-priority service disciplines and *non-work-conserving* using priority service disciplines.

In order to develop QoS-oriented MAC protocols for all-IP/ATM mobile applications, Markhasin (2001) shows that one has to overcome three main impediments:

- the time barrier: concerning the degradation of long-delay MAC efficiency when the round-trip time is significantly increased;
- the dynamical barrier: concerning the instability of the dynamic on-the-fly control of QoS provisioning; and
- the economic barrier: concerning the unacceptably large cost of the wireless broadband ATM networks with centralized architecture.

A SURVEY OF MAC PROTOCOLS

The main goal of this section is to provide an overview of various proposed MAC protocols and to compare them in terms of their ability to provide mobile users with QoS guarantees. Historically, *ALOHA* was the first MAC protocol offered for packet radio networks proposed (Abramson, 1970). It is classical *free (random) access* protocol. Unfortunately, the maximum throughput of this protocol is only 1/2e. Some two years later, the well-known *slotted ALOHA*, which doubles the efficiency of ALOHA, was offered (Roberts, 1972). The next fundamental contribution was the development of several *carrier-sense* protocols, known generically as CSMA (Kleinrock & Tobagi, 1975). Some multi-access methods, later referred to as slotted and non-slotted ALOHA and CSMA, were proposed and analyzed (Markhasin, 1969). There also the *slotting effect* about protocol efficiency increasing was opened. Rubin (1979), Tobagi (1980) and others show that the majority of other classical *free*, *controlled*, and *hybrid* access methods were also proposed in the 1970s-1980s.

The first generation of MAC protocols was not QoS-aware. Some adjusting mechanisms were used for adapting the time intervals division mainly to burst data traffic. Differentiation and service quality control problems were raised in the 1980s for integrated packet radio and satellite networks (Rubin, 1979; Li, 1984; Markhasin, 1985). The development of asynchronous transfer mode (ATM), along with multimedia information technologies and *m-applications*, triggered an interest in guaranteed QoS control. Wong et al. (2003) noted that much research has been focused on hard QoS provisioning of integrated services. For *short-delay wireless media*, *hard QoS-aware* demand assignment protocols SFRs type, including DQRUMA (Karol, Liu & Eng, 1995) and others (for an overview, see Gumalla & Limb, 2000). The TBQF scheduling scheme for wireless packet-switched networks, which provides *soft QoS* guarantees for heterogeneous traffic, was also proposed (Wong et al., 2003).

The soft QoS-oriented multifunctional medium access control (MFMAC) technology for *long-delay satellite mediums* was proposed by Markhasin (2001), who also introduced MFMAC technology based on soft QoS-aware RS-token broadcast reservation (TBR-RS) MAC protocol (Markhasin, 1996). This protocol uses the recur-

Table 1

a) MAC classification matrix with protocol examples

Access regulation mechanism \ Time process access to medium		Stochastic access process: Continuous process	Stochastic access process: Discrete process – Definite frame	Stochastic access process: Discrete process – Adaptive frame	Deterministic (Fixed) access process
Controlled access	Centralized controlled access	Non-slotted Polling	DAMA, FPODA, ARDA, SFR	Slotted Polling	S-TDMA, PAMA
Controlled access	Distributed controlled access	Non-slotted Token-passing	Superframe Reservation (SFR)	RS-Token Broadcast Reservation, MLMA	JTIDS
Free (Random) access	Carrier insensitive	Pure ALOHA	Slotted ALOHA		
Free (Random) access	Carrier sensitive	Non-slotted CSMA	Slotted CSMA ($v_0 = 1$)	Slotted CSMA, Ethernet	
Hybrid access (controlled/free)		ALOHA/ Polling	DSA_{++}, GPRS DQRUMA, TBFQ	Reserved ALOHA, MASCARA	

b) The examples of MAC protocol short-delay efficiencies

Access regulation mechanism \ Time process access to medium		Stochastic access process: Continuous process	Stochastic access process: Discrete process – Definite frame	Stochastic access process: Discrete process – Adaptive frame	Deterministic (Fixed) access process
Controlled access	Centralized controlled access	$1/(1+v_{large})$	$1/(1+v_s N/J)$	$1/(1+v_{middle})$	$1/(1+v_{small})$
Controlled access	Distributed controlled access	$1/(1+v_{middle})$	$1/(1+v_s N/J)$	$1/(1+v_{small})$	$1/(1+v_{small})$
Free (Random) access	Carrier insensitive	$1/2e$	$1/e$		
Free (Random) access	Carrier sensitive	$1/(1+a_{cf} w_{small})$ $a_{cf} > 1$		$1/(1+a_{af} w_{small})$ $a_{cf} > a_{af} > 1$	
Hybrid access (controlled/free)		$\frac{1}{1+a_{ch} w_{large}}$ $a_{ch} > 1$	$\frac{1}{1+a_{dh} w_m N/J}$ $a_{dh} > 1$	$\frac{1}{1+a_{ah} w_{middle}}$ $a_{ah} > 1$	