Guaranteed Quality-of-Services Wireless Access to Broadband Networks[1]

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Abstract

A series of study to design guaranteed quality-of-service wireless access to broadband networks has been presented in this paper, based on randomly addressed polling and its generalized expansion multiple access protocol.

I. Introduction

Wireless communications research has got into a new era. With the tremendous success of wireless cellular voice communications and the need for broadband multimedia information systems, researchers all over the world are working hard to develop wireless broadband networking technologies to serve the need in the next century. Figure 1 depicts the basic model of wireless broadband networks discussed in this paper. However, the nature of wired backbone networks and wireless access to broadband backbone is so different that one of the primary challenges in designing wireless broadband networks lies in how to guarantee end-to-end quality of service (QoS) for CBR, VBR, and ABR traffic. Future broadband backbone networks are typically realized by packet switching technology, while traditional QoS constraints are usually guaranteed by circuit-switching concept. Such a contradiction has even severe in wireless broadband networks. The main obstacle comes from how to guarantee QoS in wireless access due to the nature in wireless transmission and networking. Wireless networking has unique features to create research challenges:

- Wireless links: Typical wireless links suffer from severe fading, shortage of enough bandwidth for transmission, propagation constraints, interference, and distortion. Therefore, low bit error rate physical transmission like optical fiber is not always possible. The networking design criterion would be different.
- Mobility: Wireless access allows stations/nodes in the networks to move around. It induces a special feature in wireless networks known as mobility management. In other words, network topology is dynamically changing as stations move in/out cell coverage or turn on/off the transmission. A more complicated scenario is multimedia terminals to transport all possible CBR, VBR, and ABR traffic, which is the scope of this paper.

The rest of this paper tries to summarize a series of effort to provide guaranteed QoS wireless access to broadband networks such as ATM networks and others with end-to-end QoS constraints. End-to-end QoS requirements can be divided into two parts: within the wired broadband network and in wireless part. The latter obviously plays a dominant role due to the features of wireless networking stated in above.

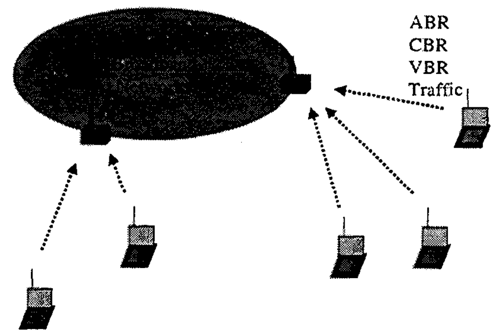

Figure 1 Wireless Access to Broadband Networks

II. Multiple Access in Wireless Broadband Networks

A well known, straightforward, and widely accepted approach to design wireless access protocols in wireless packet switching broadband networks typically consists of a random access scheme for initial call set-up and possibly ABR traffic transport, and certain reservation scheme to create certain logical circuit-switching connections. One of the very first proven concept of such an approach was done by well known packet reservation multiple access (PRMA). PRMA was not even a new concept at the time when D. Goodman proposed it. It is actually a combination of ALOHA and TDMA reservation, which might be traced back as R-ALOHA in early days of computer networking research. However, PRMA indeed provides an important step in wireless networking research as it demonstrated that packet switching by random access with reservation can grant effective connections for on-off CBR traffic, later adding data traffic. In spite of overwhelmingly popular in related PRMA research, the largest challenge in wireless broadband access lies in how to support VBR traffic that might dominate the wireless transmission bandwidth, in addition to CBR and ABR traffic. Although some investigations have been conducted, it still

[1] This research was supported by the National Science Council under a research grant.

0-7803-4872-9/98/$10.00 © 1998 IEEE

remains pretty open in communication research, while most existing work consider fixed super-frame structure and ALOHA family random access protocols that suffer a lot for unsatisfactory delay characteristics.

In the past a few years, a series of efforts have been conducted toward a new random access mechanism originally primarily designed for wireless networks and those networks with topologies that distributed transmission/carrier sensing is not reliable. From this research, a general concept has been developed for multiple access protocols, which is known as MULCAR (multi-layer collision avoidance and resolution) consisting of two kinds of tree expansions based on collision avoidance (such as carrier sensing or its generalization) and collision resolution. One of the best examples to conform this concept is the group randomly addressed polling (GRAP) that implements both collision avoidance expansion and collision resolution expansion. Many other protocols only implement one of the expansion techniques/trees such as auction demand multiple access [2]. It may also account why CSMA/CD is good due to its simple realization of both expansions. However, different from many research approaches, we believe that an effective random access is always the basis to design wireless access protocol to meet QoS constraints due to its fundamental role. In this paper, we shall use such an efficient random access protocol family (RAP or GRAP) as the fundamental access that primarily serves ABR and initial connection setting up. The concept of applying RAP/GRAP/MULCAR is not only for efficiency consideration but also for reliable operation. In order to serve CBR and VBR traffic effectively, false of transmission coordination (multiple access) such as hidden terminal problem for CSMA, and reliable bandwidth allocation that is usually done in centralized way for wireless networks due to their dynamic characteristics, are primary concerns to design guaranteed QoS wireless access. RAP family protocols is initiated in a distributed way but is transformed into a centralized polling turns out capable of successfully carrying out above two issues.

III. Polling with Non-preemptive

The most initial trial of guaranteed QoS wireless access based on the RAP family protocols is known as polling with non-preemptive (PNP). The fundamental idea is to use conceptual polling tokens to control CBR and VBR traffic, while the ABR traffic that might contain critical traffic information and other message with time constraint is exchanged based on the efficient GRAP. It is more or less considered as a combination of RAP random access and a round-robin reservation of logic bandwidth units. To design the PNP wireless access, we assume

1. All packets have the same size.
2. A CBR traffic source is characterized by (γ,δ), where γ is the rate of source and δ is the maximum tolerable delay. Packets generated periodically are stored in the ready-to-transmit buffer.
3. A VBR traffic source is characterized by (ρ,σ,d), where ρ is the average rate, σ is the maximum burstiness, and d is the maximum tolerable delay. A VBR source is regulated by a (σ,ρ)-leaky bucket. Only packets passing through the leaky bucket can be stored in the ready-to-transmit buffer.
4. An ABR traffic source has neither a jitter constraint nor a delay constraint. All ABR traffic sources share the remaining bandwidth from CBR and VBR sources in a fair and efficient way.

The associated admission control for CBR and VBR traffic is simple as a traffic can be admitted only when its maximum delay constraint can be honored for every packet that it might generate. The algorithm for PNP operation is summarized as follows:

1. For each CBR source, its polling token is generated every $1/\gamma$ in base station.
2. For each VBR source, its first polling token is generated p second (suggested $p=d/2$) after connection is set up.
3. When a transmission ends, the base station performs:
   (a) The base station scans the polling token buffer for CBR courses according to a preset priority. If a polling token is found, removes the token and polls the CBR course.
   (b) If no token for CBR sources, scan VBR token buffer according to a preset priority. If any token is found, proceed the polling.
   (c) When no token is found in CBR and VBR sources, start services for ABR based on GRAP.

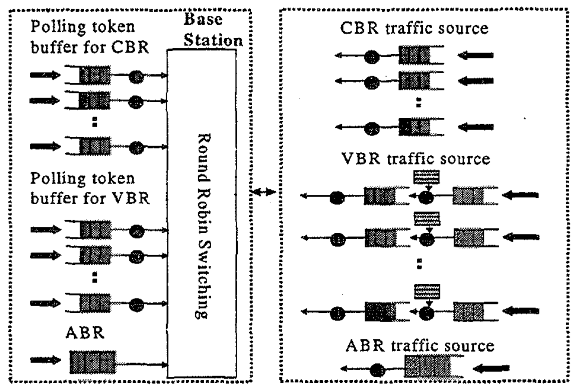

Figure 2 PNP Operation

In general, each polling token represents one packet transmission from the buffer. At the end of each VBR message, an end-of-file is transmitted and the base station removes the polling token and sets up to generate next polling token. Although the priority setting in this method is not needed, by using this simple rule, successful wireless access to guarantee QoS is achieved with proof from both simulations and mathematical bounds [3].

IV. General Processor Sharing Concept

Instead of combination of random access and reservation, another view to tackle QoS control is just to treat the available radio resource as a bandwidth allocation for all traffic sources. Its best possible allocation is naturally a solution. For this purpose of bandwidth allocation, Packet-by-Packet Generalized Processor Sharing algorithm (PGPS) [4] is well known for its flexibility, efficient sharing of resource, and is considered as a promising switching scheme to guarantee QoS in wired broadband networks. Therefore our next logical scheme is PGPS/RAP multiaccess [5], in which we use the PGPS scheduler to dynamically reserve bandwidth for VBR and CBR traffic in contrast to the straightforward frame-structure reservation schemes. Again, RAP random access protocol serves as the access scheme for initial call setup and the ABR service. As the rate of VBR traffic is inherently time-invariant, a feasible solution is to reserve the peak rate for each VBR stream. Although this approach may seem too conservative and not aggressive enough, PGPS scheduler's ability of dynamical bandwidth allocation enables PGPS/RAP to switch the surplus VBR bandwidth to ABR when VBR traffic is in its low-rate period. Thus in PGPS/RAP multiaccess, CBR traffic occupies a fixed amount of bandwidth while VBR and ABR share the remaining bandwidth according to the rate of VBR traffic.

To use the centralized PGPS scheduler in a wireless channel where the queues used to accommodate incoming packets are distributed, the basic idea is to generate different kinds of permits according to the traffic parameters obtained at the call setup time and then use the PGPS scheduler to arbitrate the use of the channel. A primary difference between this idea and PNP scheme is that the static priority is replaced with the more flexible weighting factor concept of PGPS scheduler. Please note that we can not apply PGPS concept directly as the non-transparent queue problem caused by distributed wireless mobile sources. We must modify the algorithm based on the initial setup head packet. Under PGPS/RAP multiaccess, we assume:

1. The channel capacity is C bps
2. All packets generated from a source are of the same size.
3. The packets of all ABR traffic sources are of the same size but the packet of CBR or VBR traffic sources may be of different size.
4. There exists a fixed parameter L_{max}, which is a size upper bound of all packets.

A CBR traffic source is characterized by four parameters (r^c_i, L^c_i, T^c_i, D^c_i), where r^c_i (bps) is the rate of this source, L^c_i is the size of packets of this source, T^c_i is the packet interarrival time, D^c_i is the maximum tolerable delay. A CBR grant permit is generated every T^c_i seconds. A VBR traffic source is characterized by five parameters (r^v_i, L^v_i, T^v_i, Q^v_i, D^v_i), where r^v_i (bps) is the peak rate of this source, L^v_i is the size of packets of this source, T^v_i is the minimum packet interarrival time, Q^v_i is the query packet size of this source (explained later), D^v_i is the maximum tolerable delay. For VBR, a query permit is generated every NT^v_i seconds, where N is optimized such that the maximum delay is satisfied and the query operation occupies the least bandwidth. Then grant permits are generated after each query permit in accordance to its query result. Consequently, the PGPS/RAP multiaccess is stated as follows:

1. Given the permit generating mechanisms stated above, set the weighting factor ϕ^c_i of the *ith* CBR source to r^c_i; set the weighting factor ϕ^v_i of the *ith* VBR source to $r^v_i(1+Q^v_i/NL^v_i)$, and set the weighting factor ϕ^a of the ABR queue to $C-\Sigma\phi^c_i-\Sigma\phi^v_i$.
2. Use a PGPS scheduler to select a permit to servie
   2.1. if the permit is for the *ith* CBR user, the base station notifies the *ith* CBR to transmit a packet.
   2.2. If the permit is for the *ith* VBR, and
      2.2.1. it is a query permit, the base station queries the *ith* VBR how many packets arrive in last NT^c_i seconds.
      2.2.2. it is a grant permit, the base station notifies the *ith* VBR to transmit a packet.
   2.3. If the permit is for the ABR service, the base station notifies all ABR users to transmit their random addresses or polling next active address base on RAP protocol.
3. Go to 2.

If the weighting factors of PGPS are assigned according to our proposal, PGPS/RAP can be proved to guarantee worst-case delay of CBR and VBR traffic and thus provides guaranteed QoS for delay-sensitive CBR and VBR traffic in multimedia wireless networks. The QoS GPS provides is fairness and guaranteed bandwidth. Another different feature for this appraoch is no need for superframe-structure under the processor sharing concept, which supports more flexibility (and thus efficiency) in network design. In the past a few years, there are more and more research in scheduling algorithms guaranteeing more general QoS such as service curve, and we believe that these research provide many useful improvements to our wireless multiaccess schemes.

V. Control Using Markovian Property of MULCAR

Up to this point, we are considering methodology to control QoS from bandwidth management concept. Such a concept usually implies a sort of reservation mechanism in wireless multiple access. However, this might be suitable for all kinds of design (such as non-preemptive multiple access in ETSI's HIPERLAN) and might not account for all possible approaches toward wireless QoS concern. By looking at the most concerned issue in QoS constraints, we try hard to make sure the delay within the satisfactory limit. Due to MULCAR described earlier that can pretty much represent most multiple access protocols, a valuable scenario is to develop a general methodology to control delay-sensitive traffic in a unified view. It is lucky that a Markov chain model can describe the dynamics of MULCAR. With such a feature, the dynamic characteristics of delay sensitive traffic is represented by a Markov chain. Its control mechanism over MULCAR is naturally an effective wireless broadband access.

MULCAR consists of two kinds of expansion in terms of multiple access implementation: collision avoidance/anticipation with feedback information of transmission or no transmission; and collision resolution with channel information idle, success, collision. We can use different ways to divide users into groups to reach effective channel access. Figure 4 shows examples of existing protocols in form of MULCAR. Our goal is thus clear to design efficient random access sensitive to system condition allowing real-time admission for new arriving traffic. Since the control is based on the splitting of groups that can be pre-calculated from Markov chain describing delay behavior, the algorithm of MULCAR combining feature-domain grouping and reservation can be summarized as follows [6]:

1. Base station updates the time τ since last ending of processing real-time traffic group.
2. Based on the comparison of τ and delay-bound, we decide the operating mode that corresponds to the shape and completeness of collision avoidance expansion and collision resolution expansion.
3. Base station polls traffic in real-time reservation list.
4. Based on the tolerable dropping rate and calculated limit of delay, determine the number of groups in operation for wireless access.

Please note that the way to implement grouping really relies on the operating environment, radio resource, and affordable system complexity. Above methodology can be adopted to these practical constraints to yield a final design.

VI. Conclusions

In this paper, we presented a series of our recent study toward guaranteed QoS wireless access to broadband networks from different points of view. All of these approaches are numerically and mathematically justified. This by all means is not the end of research, but is the starting toward the final practical solution.

Acknowledgment

The authors would like to appreciate Professor C.S. Chang at the Department of Electrical Engineering, National Tsing Hua University, Taiwan, for his helpful discussions.

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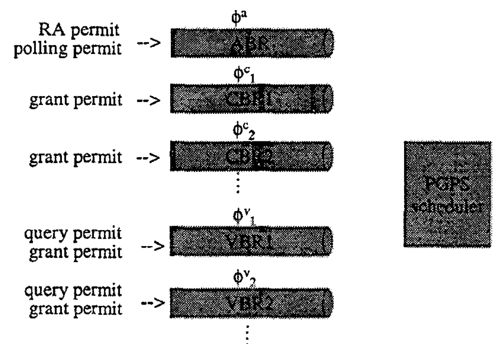
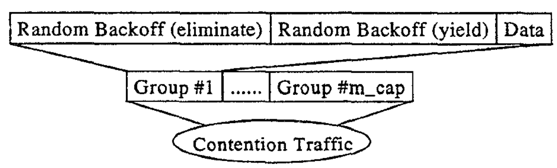
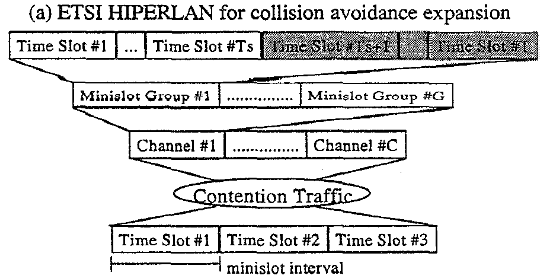


Figure 3 PGPS/RAP multiaccess



(a) ETSI HIPERLAN for collision avoidance expansion



(b) IEEE 802.14 for collision avoidance & collision resolution expansion

Figure 4 Examples of MULCAR