Paper

Analysis of bandwidth reservation algorithms in HIPERLAN/2

Józef Woźniak, Tomasz Janczak, Przemysław Machan, and Wojciech Neubauer

Abstract—This paper focuses on performance of channel access methods in the HIPERLAN/2 standard. It discusses commonly used approaches to bandwidth allocation and presents a modified algorithm for effective bandwidth management based on pre-scheduled resource grants. Simulation results show that the new algorithm ensures much higher throughput compared to the standard method.

Keywords—HIPERLAN/2, MAC, bandwidth allocation, QoS.

1. Introduction

Wireless LANs have gained market acceptance over the last several years, partly because of the increased demand for wireless communications and advances in portable computers and networking technology. Although the first WLAN solutions were used as a cordless replacement for Ethernet networks, it is clear that in the near future WLANs will have to keep up with the growing demand for bandwidth-consuming multimedia traffic. In particular that means effective support for service differentiation.

Today, two institutes lead the development and standardization of wireless LANs, namely the Institute of Electrical and Electronics Engineers (IEEE) and European Telecommunications Standards Institute (ETSI). Since 1996, when IEEE first published the 802.11 standard [6] offering 2 Mbit/s data rate, a lot of work has been done to increase the transmission speed. The IEEE 802.11b supplement, published in 1999, enhances available data rates to 5 Mbit/s and 11 Mbit/s. Another IEEE group developed the 802.11a version, which exploits the orthogonal frequency-division multiplexing (OFDM) technique to achieve data rates up to 54 Mbit/s. Although IEEE 802.11 defines a number of new physical layers, the originally proposed MAC protocol remains untouched. This approach promotes compatibility, but it retains the legacy MAC layer that lacks effective quality of service (QoS) support.

While IEEE worked on 802.11, ETSI proposed the high-performance radio LAN (HIPERLAN/1) standard, offering up to 18 Mbit/s data rate [1]. Unlike the 802.11 solution, the HIPERLAN/1 MAC protocol uses frame priorities, and thus it has means to support quality of service differentiation. This allows HIPERLAN/1 to effectively transmit a variety of information types, such as data, video and voice. In spite of this advantage, HIPERLAN/1 devices were never introduced. Therefore, ETSI developed the HIPERLAN Type 2 solution [2] which had a number of attractive features as compared to 802.11a. One of them is higher throughput. As both 802.11a and HIPERLAN/2 use the same OFDM coding technique they reach the same maximum data rates of 54 Mbit/s at the physical layer. However, from user perspective the maximum throughput of HIPERLAN/2 is 42 Mbit/s, whereas throughput of 802.11a is only around 18 Mbit/s. The other significant differences are on MAC layers. IEEE 802.11 implements distributed CSMA with collision avoidance. HIPERLAN/2 (H/2) employs a central controller to coordinate transmissions. Like the first version, HIPERLAN/2 inherently supports quality of service differentiation.

Although, IEEE 802.11 seems to prevail on the market now, it is possible that the advantages of HIPERLAN/2 will attract attention of customers, especially in the face of growing throughput demand [8].

In this paper, we analyse the efficiency of bandwidth allocation methods in HIPERLAN/2. We also introduce a new allocation scheme that significantly increases the overall network throughput.

This paper is organized as follows:

- Section 2 outlines the HIPERLAN/2 architecture.
- Section 3 discusses the original bandwidth allocation scheme.
- Section 4 describes the modified algorithm.
- Section 5 presents simulation results that compare performance of both solutions.
- Section 6 concludes the paper.

2. HIPERLAN Type 2

HIPERLAN/2 is intended for short-range, high-speed radio communication systems with data rates from 6 Mbit/s to 54 Mbit/s. It connects portable devices with broadband networks based on IP, ATM, and other technologies [11]. H/2 specifications cover two lowest layers of the OSI model, namely the physical (PHY) and the data link control (DLC) layer. Figure 1 illustrates the protocol stack. Furthermore, the DLC specification is split into two parts:

– basic MAC protocol [3],

– radio link control services (responsible for connection maintenance).

A convergence sublayer between DLC and upper layers adapts the H/2 to existing network architectures. The convergence options currently considered are:

– packet based networks, either Layer 2 (Ethernet) or Layer 3 (IP),

– cell based networks (ATM) standardized by the ATM Forum,

– UMTS based services, developed by the 3GPP partnership project.

The medium access control (MAC) protocol operates in a centralized manner, where a single node controls data transmission in a subnetwork cell. In a business environment, all terminals communicate using a fixed access point (AP). In a home environment, the capability of direct link communication is provided within a single subnet [4]. HIPERLAN/2 uses this mode to create ad hoc subnetworks without relying on the cable infrastructure. In this case, a central controller (CC) is dynamically selected from the portable devices. The CC node is capable of supporting multi-media applications by providing mechanisms to handle QoS reservations and allocate bandwidth, same as AP [5]. There is also a proposed solution for inter-subnet forwarding [9, 10].

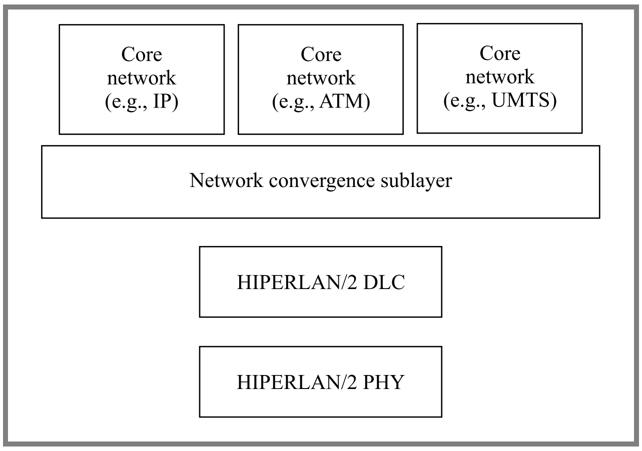

Fig. 1. HIPERLAN/2 protocol stack overview.

In both modes, the medium access control protocol employs a dynamic TDMA/TDD scheme. The MAC frame has a fixed length of 2 ms. An AP or CC node generates the frame structure, as illustrated in Fig. 2.
Each MAC frame comprises:

- **Fixed broadcast channel (BCH)**. This is a downlink channel that identifies AP/CC and a subnet. Broadcast channel denotes the beginning MAC frame.

- **Variable-length frame channel (FCH)**. It describes the structure of the MAC frame in terms of resource grant (RG) messages. RGs hold information about the assigned short channels (SCHs) and long channels (LCHs) in data transmission phases. RGs also inform that a MAC frame contains data that must be received by a particular mobile station in the subnetwork.

- **Variable-length access feedback channel (ACH)**. The ACH stage informs terminals about the results of the contention-based access attempts in RCH slots of the previous frame. ACH includes a bit field; if a bit corresponding to RCH is set the transmission was successful. Otherwise, a collision has occurred.

- **Downlink (DL), direct (DiL) and uplink (UL) data transmission phases**. These phases include SCH and LCH slots. The SCH slot is used to control traffic, while the LCH slot carries user data traffic. If a direct mode is used, the MAC frame can also contain a DiL phase, inserted between the DL and UL phases.

- **At least one random channel (RCH)**. The RCH slots make it possible for the terminal to send unsolicited control information to AP/CC, such as resource reservation (RR) messages. Nodes access RCH on a contention basis, according to the back-off algorithm. Additionally, stations use RCHs for the first contact with AP/CC to register themselves in a subnet.

The existing resource reservations and a scheduling algorithm determine the structure of a MAC frame, except for RCH. As a result, to maximize the overall bandwidth, the number of RCH slots should be kept to a minimum. However, the optimal number of RCHs depends on the current traffic load. In particular, it should be dynamically adjusted to the number of stations using these slots.
The RCH access algorithm employs a contention window scheme. Initially, a station sets the window size to n. If a station fails to access the RCH slot, it changes the window size according to the number, a, of unsuccessful attempts. Next, the station selects a random number from the range $< 0,\ CW_a >$:

$$CW_a = \begin{cases} 256 & 2^a \geq 256 \\ 2^a & n < 2^a \leq 256 \\ n & n \geq 2^a \end{cases} .$$

The selected value corresponds to the RCH slot in the current MAC frame or in one of the successive frames. After the transmission, station waits for positive feedback in FCH.

Bandwidth allocation. To control the allocation of network resources, AP or CC needs to know the state of its own buffers and buffers in the mobile terminals (MTs). MTs report their buffer states in resource request messages sent to AP or CC. Optionally, MT negotiates a fixed capacity allocation upon connection establishment. In this case, a mobile terminal does not need to explicitly request resources with RR messages.

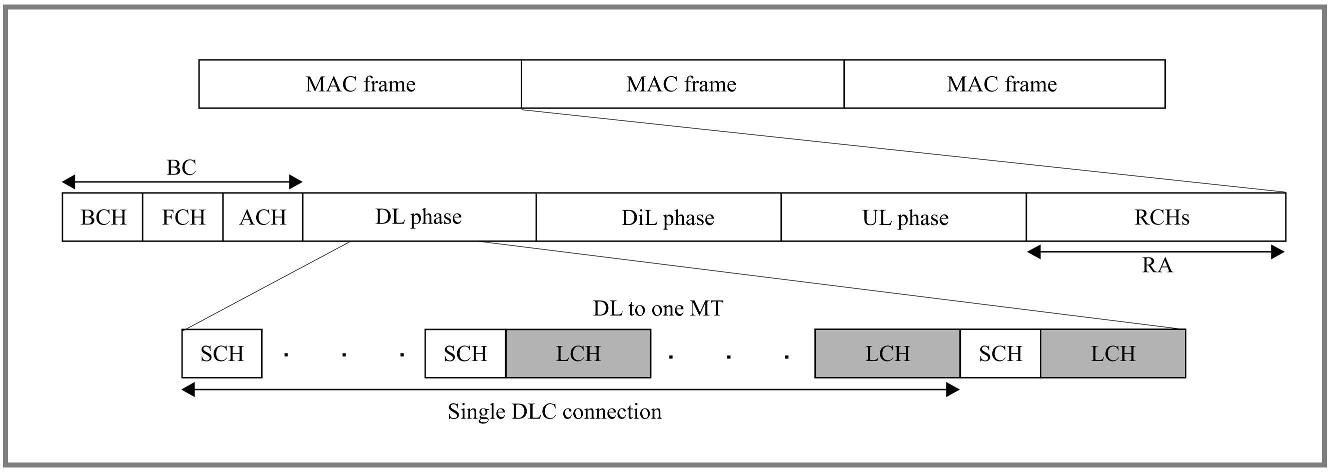

Fig. 2. Generic structure of a MAC frame in HIPERLAN/2.

In response to RR messages (or negotiated capacity), the AP/CC node allocates resources to mobile terminals. The central node should allocate the resources according to the buffer states and, if required, take quality of service parameters into account. The allocated resources are announced in resource grant messages, transmitted in the FCH phase. According to [9], three classes of MAC scheduling algorithms are considered:

– static resource allocation,

– dynamic resource allocation,

– priority-based scheduling (a combination of the above).

The static allocation guarantees transmission of a specified number of LCHs and SCHs per MAC frame. A disadvantage of this method is the low flexibility in changing capacity demand. The H/2 standard provides two algorithms of this class:

– fixed slot allocation (FSA),

– fixed capacity agreement (FCA).

In both functions the estimated capacity is negotiated while connecting. FSA is only available in home extension of the H/2 standard [4]. It assumes that a fixed part of a MAC frame is assigned to the particular connection. If the resource demand changes, the allocation can be adjusted by a connection modification procedure. The FCA function periodically assigns a number of LCHs and SCHs for a connection. The agreement can be adjusted by using RR messages.

Implementations of dynamic bandwidth allocation in the H/2 standard are based on resource request messages generated by stations. RR messages convey the current state of the DLC transmission buffer. Each station maintains a separate logical buffer for every DLC connection. According to the H/2 standard, RR messages can be carried in SCH slots granted to a station or in a randomly chosen RCH slot. However, ETSI does not recommend the use of RCH for RR messages.

There are several methods proposed for an AP/CC station to perform dynamic allocation; such as round-robin and its modifications [7]. Non-exhaustive round-robin assigns one LCH for every DLC until the MAC frame is completely filled. Exhaustive round-robin serves the first connection completely until the next connection is considered.

Priority-based scheduling is a combination of static and dynamic resource allocation. For example, the H/2 Ethernet convergence layer recommends using of 802.1p traffic priorities. In this case, a scheduling algorithm allocates a different number of LCHs for every DLC (based on connection priority).

3. Standard bandwidth allocation

This section describes the proposed resource allocation method in the HIPERLAN/2 standard. The method assumes that RR is carried in SCH if it has been assigned by the scheduling algorithm in AP. Otherwise, MT selects the RCH slot to send a resource request message to AP, as shown in Figs. 3 and 4. In response, AP allocates one additional SCH (exclusively) to the RR message.

Several simulation experiments have been carried out to verify the effectiveness of the standard method. In each experiment, a scenario with one hundred MTs and one AP was examined. Every mobile station established one best effort DLC connection with AP. The best effort traffic was modelled as a Poisson source of fixed-length packets. Moreover, all stations generate traffic streams of the same intensity. The traffic stream is injected under Ethernet service specific convergence sublayer. The lengths of the SSCS frames are 1500 bytes, 500 bytes and 60 bytes.

Figure 5 illustrates throughput characteristics of the 1500-byte-long SSCS frames. The expected behaviour is that net-

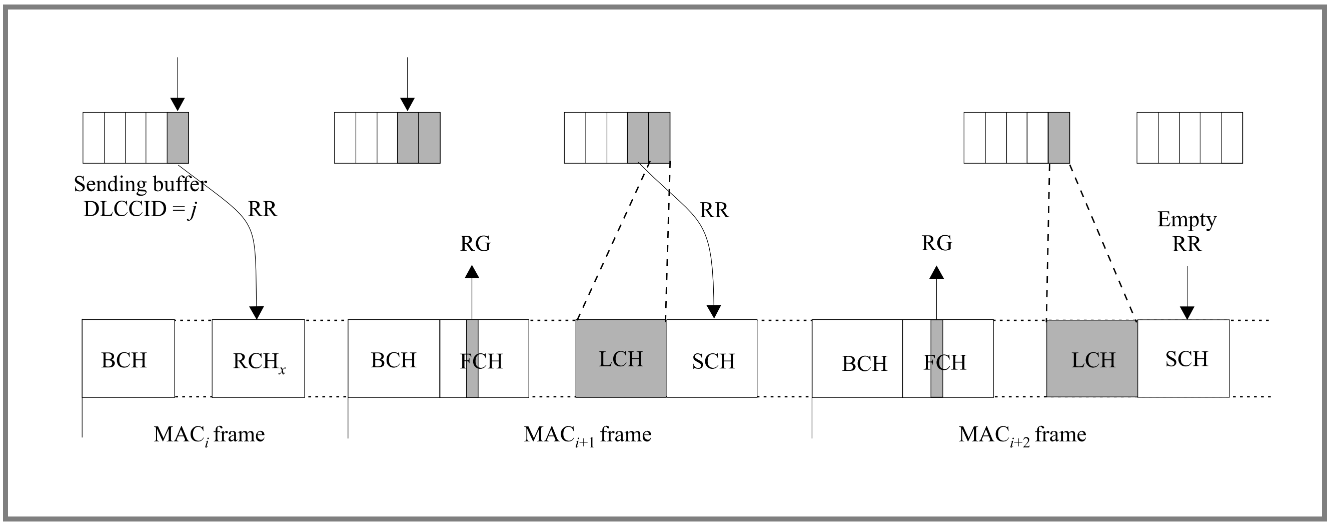

Fig. 3. Original algorithm.

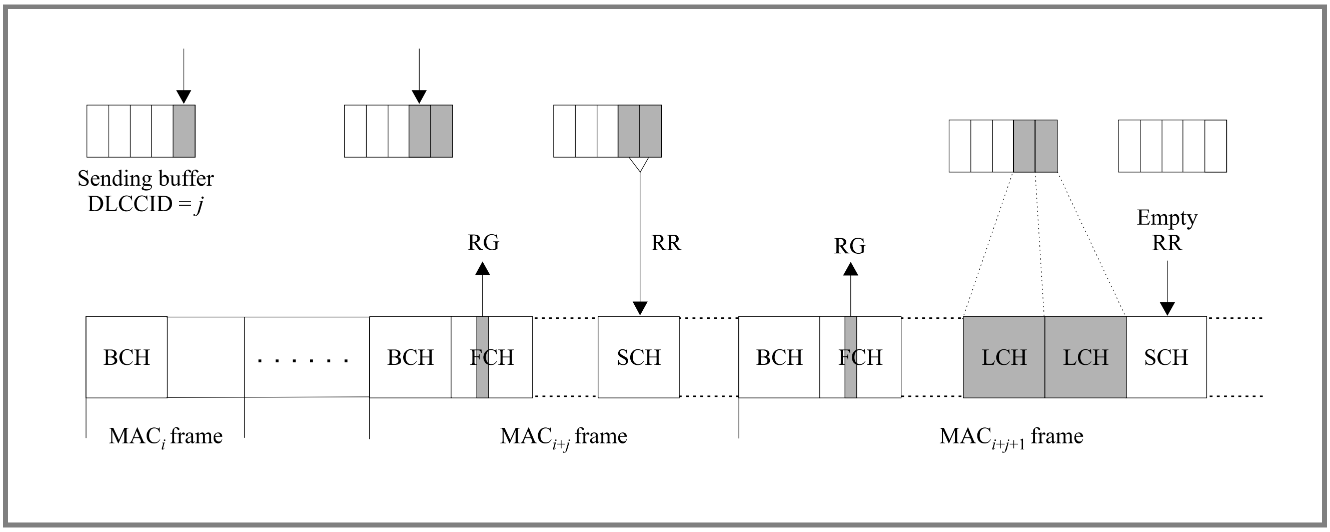

Fig. 4. Modified algorithm.

work throughput will be proportional to the total traffic load up to the network saturation point, and then constant beyond the saturation point. However, as shown in Figs. 5, 6, and 7, even 5 RCH slots are not enough to assure the desired throughput characteristics before the saturation point. Basically, if the number of RCH slots is too small, stations have to wait a long time before sending RR messages. Moreover, because of the enormous number of collisions in the RCH phase, a lot of shared bandwidth is wasted. The network resources are utilized better as the number of slots increases. However, there is an obvious trade-off between the number of slots in RCH and the bandwidth available for the user data. The optimal number of RCH slots can be estimated as a balance point between the low number of collisions and the high bandwidth utilization.

Unfortunately, the optimal number of slots strongly depends on the length of the SSCS frame (as shown in Figs. 6 and 7). Furthermore, in case of heterogeneous traffic the problem becomes even more complicated, because the optimal number of RCH slots for 1500 byte frames is not the same as for 60 byte frames. As a result, adjusting the optimal number of slots to current load conditions becomes a non-trivial issue.

Given such conclusions, we developed a solution that does not rely on dynamic adjustment of RCH slots. Instead, the modified algorithm tries to minimize the number of RCH users, thus decreasing the frequency of collisions and the amount of wasted bandwidth.

4. Modified algorithm

In the standard algorithm, the problem of bandwidth degradation escalates as the SSCS frame becomes shorter. This is because an RR message is sent on every transmission buffer change. From the simulation experiments it is clear

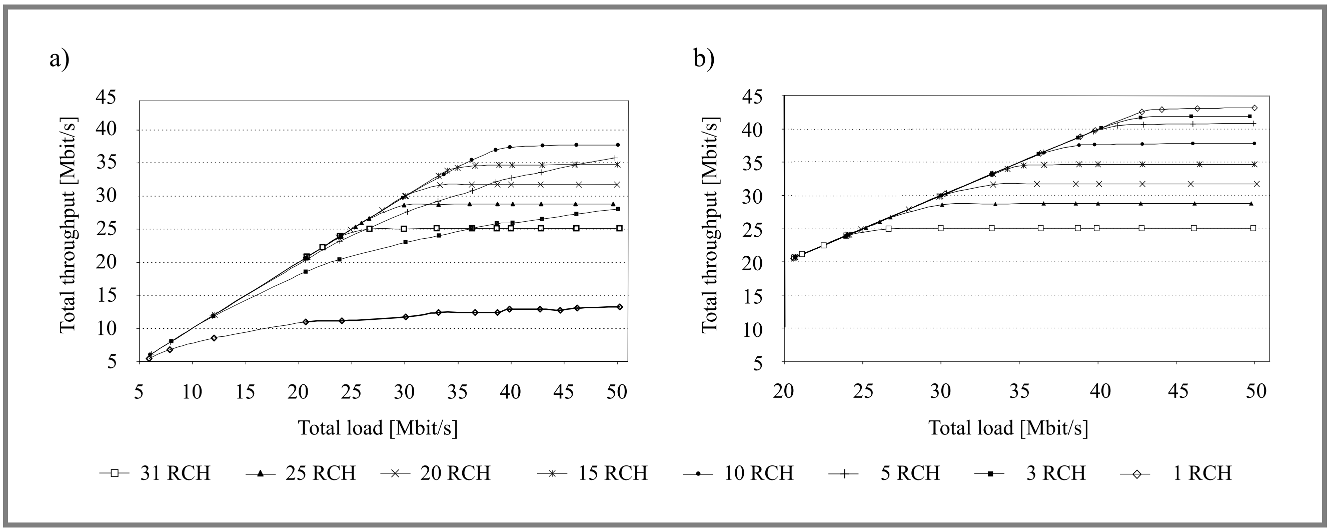

Fig. 5. Comparison of standard (a) and modified (b) bandwidth allocation methods for 1500-byte packets.

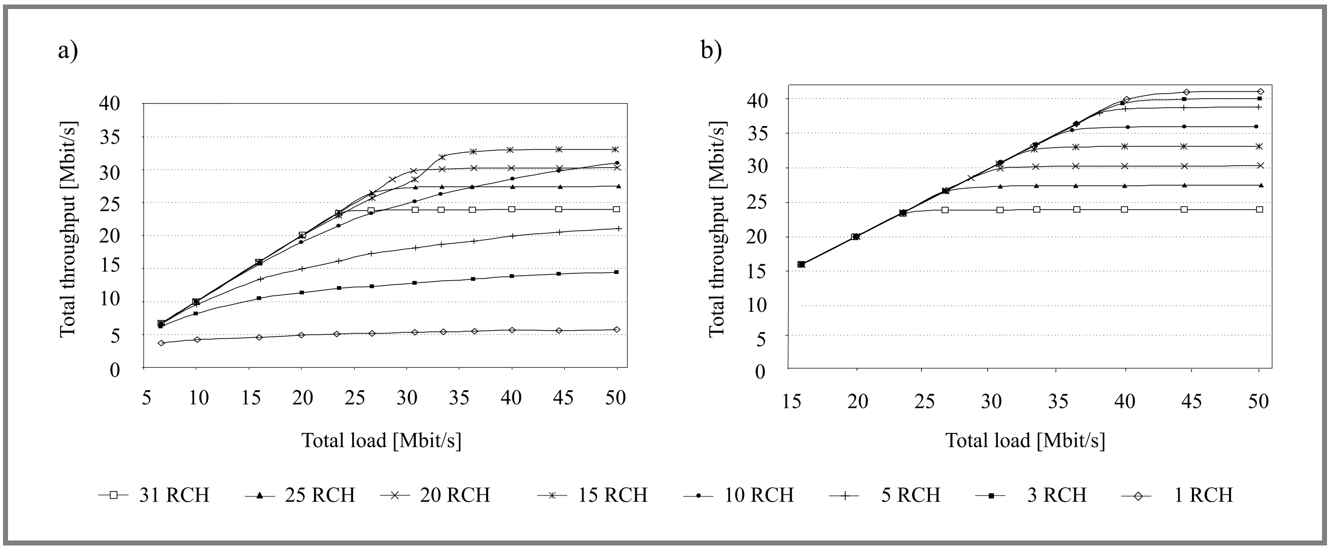

Fig. 6. Comparison of standard (a) and modified (b) bandwidth allocation methods for 500-byte packets.

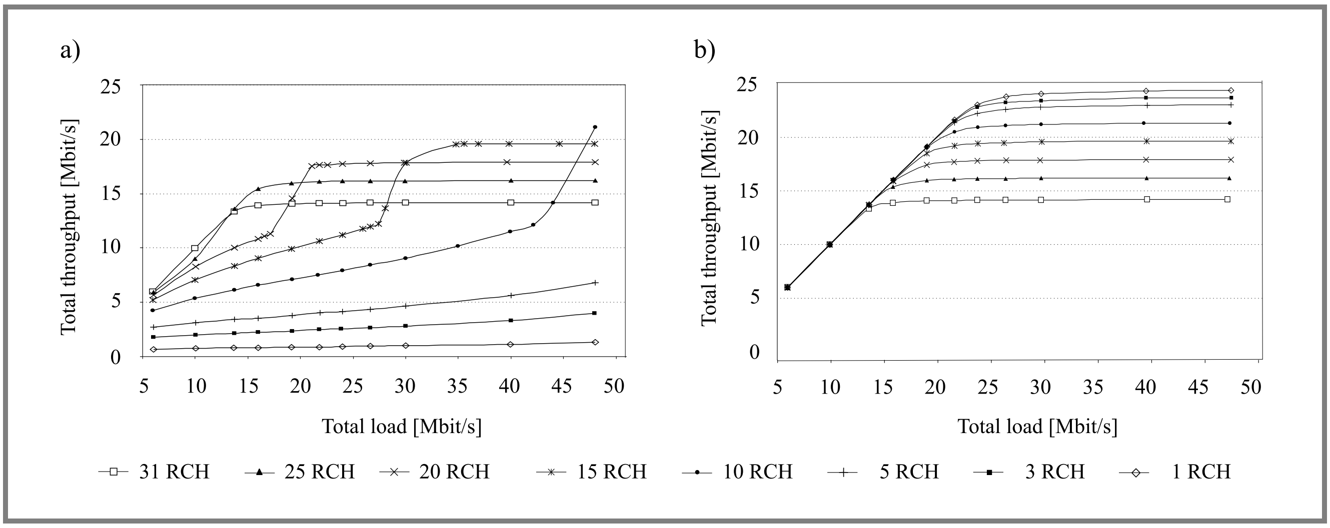

Fig. 7. Comparison of standard (a) and modified (b) bandwidth allocation methods for 60-byte packets.

that stations tend to use RCH rather then SCH channels, as data packets become shorter. The increasing number of RCH access attempts results in more collisions, which in turn causes non-optimal bandwidth utilization.

The modified method (Fig. 4) assumes that stations do not use RCH slots to send RR messages. To avoid the overflow of station transmission buffers, AP periodically polls MTs for their buffer status. To poll a station, AP arbitrarily allocates SCH for inactive DLC connections. A connection is considered inactive if there were no resources granted to it in the previous MAC frame. In a granted SCH channel, a station reports the number of LCHs needed to service the buffered frames. The modified method increases the chance that a station uses SCHs instead of RCH to communicate resource requests. However, RCH cannot be eliminated completely (for example, RCH is used for DLC connection set-up).

AP allocates SCH to poll stations using the round robin algorithm. The algorithm periodically allocates one SCH for each inactive connection. If there are no resources in the current MAC frame, the algorithm allocates SCH to poll a station in the next MAC frame.

The cooperation of standard and modified methods is also possible. If a station buffer state changes, the "backoff" timer is set and the station waits for SCH granted to send RR. If the timer reaches zero, and no SCH has been allocated, the station sends RR in RCH.

5. Simulation results

The modified method ensures better utilization of network bandwidth as shown in Figs. 5, 6, and 7. The new method demonstrates advantages, regardless of the frame length. Moreover, since RCH slots do not carry RR messages, the adjustment of number of slots is outside the scope of the scheduling algorithm.

In addition, the standard method has a higher probability of dropping incoming packets in comparison to the modified method. This is because of collisions in RCH slots. In the H/2 standard, RR messages convey information on one DLC connection transmission buffer. The number of access attempts in RCH is proportional to the number of DLC connections, not the number of mobile terminals.

6. Conclusions

This paper presented the current state of work on bandwidth allocation in the HIPERLAN/2 standard. A new solution was also proposed, based on pre-scheduled resource grants. The performance characteristics—obtained via simulation—prove that our algorithm ensures higher throughput compared to the standard method.

Moreover, the new proposal remains almost completely independent of the traffic pattern, making this strategy particularly suitable for supporting real-time traffic with strong QoS requirements. At the same time, the new priority-based transmission scheme does not introduce any organizational overhead to the MAC protocol.

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