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Title: COEXISTENCE OF IEEE 802.11a AND ETSI BRAN HiperLAN/2: THE PROBLEM OF FAIR RESOURCE SHARING IN THE LICENSE EXEMPT BAND AT 5 GHz

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Abstract: Frequency Sharing Rules (FSRs) or frequency etiquettes providing the fair coexistence of the two broadband communication standards ETSI BRAN HiperLAN/2 and the IEEE 802.11a are discussed in this document. Both systems are invented to operate in the license exempt band 5.1 .. 5.8 GHz in Europe and similar U-NII bands in the U.S. and Japan. Both systems focus on high speed WLANs and broadband wireless access with or without connection to a certain core network. Although the standards are mainly designed for conventional packet data transmission without delay constraint, they nevertheless enable, to a certain extent, a guarantee of Quality of Service (QoS). A scenario where both types of standards have to share the same frequencies is of considerable interest also for standardization of the Fixed Wireless Access Networks IEEE 802.16 and HiperACCESS, as these both standards are likely to get into the same field of coexistence problems. In this paper, the already upcoming standards for high speed LANs are discussed. Some issues for a better understanding of Frequency Sharing Rules are presented.

Keywords: Frequency Sharing Rules, Decentral Radio Resource Management, Game Theory

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ABSTRACT

Frequency Sharing Rules (FSRs) or frequency etiquettes providing the fair coexistence of the two broadband communication standards ETSI BRAN HiperLAN/2 and the IEEE 802.11a are discussed in this document. Both systems are invented to operate in the license exempt band 5.1 .. 5.8 GHz in Europe and similar U-NII bands in the U.S. and Japan. Both systems focus on high speed WLANs and broadband wireless access with or without connection to a certain core network. Although the standards are mainly designed for conventional packet data transmission without delay constraint, they nevertheless enable, to a certain extent, a guarantee of Quality of Service (QoS). A scenario where both types of standards have to share the same frequencies is of considerable interest also for standardization of the Fixed Wireless Access Networks IEEE 802.16 and HiperACCESS, as these both standards are likely to get into the same field of coexistence problems. In this paper, the already upcoming standards for high speed LANs are discussed. Some issues for a better understanding of Frequency Sharing Rules are presented.

INTRODUCTION

To support QoS in an environment where the different system types are also operating at the same time and frequency has up to now only a little been investigated [1–4]. How the two Wireless LANs (WLANs) IEEE 802.11a and the European ETSI BRAN HiperLAN/2 may fairly coexist without being able to communicate and without exchanging resource requests or grants, and what problems may arise if the systems just work according to their local requirements, is highlighted in this contribution. Procedures, strategies and measures taken by the systems to support QoS although competitively working with shared resources are yet to be defined by the standardization bodies. Dynamic spectrum sharing within radio systems, between uncoordinated systems of the same standard or even between systems using different technologies is attracting an increasing interest [1].

Massive growth in wireless and mobile communication, the emergence of multimedia applications as well as the demand on high-speed Internet access including mobile terminals, and the deregulation of the telecommunications industry are the key drivers towards a new demand for radio-based broadband access networks [5, 6]. According to [7], wireless communications driving the market have the potential to close the gap not only between developing and developed countries, but also between differently developed regions within a country. Broadband wireless access technologies allow the convergence of various services such as multimedia. Wireless access technologies are opening new perspectives to the global information society, providing opportunities for tele-education, tele-medicine, and many other applications which are highly beneficial for the social and economic development [8]. The approach of the license exempt frequency allocation as discussed in this work may be a strategic plan for an efficient radio spectrum policy in the future, as required in [9].

In this document, some first approaches to support the coexistence of HiperLAN/2 and IEEE 802.11a are discussed. Performance results from simulation of both standards are presented. The next section discusses the approach of shared frequency bands, Sect. shortly summarizes the key functionalities of the two involved systems. Following, Sect. explains why the etiquettes are required, and Sect. presents first approaches and results of the simulations. During this research work it has been understood that mathematics taken from

Game Theory apparently have the capabilities to model the competitive scenarios quite appropriately, leading to completely new ways of analysis and synthesis of Frequency Sharing Rules. This issue is discussed in Sect. .B. The paper ends up with a conclusion and an outlook on following work.

OPEN ACCESS AND THE APPROACH OF FREQUENCY SHARING RULES

Up to now, exclusive frequency bands have been assigned to radio systems of multiple operators with different standards are typically. These frequency bands are furthermore separated by unused frequency bands in order to avoid mutual interference. But the unused frequency bands between the systems and the fact that parts of the assigned frequencies are very often not required by one system every time and at any place results in a low spectrum efficiency.

An economically better solution considers the location and time dependent requirements on frequencies of the radio systems and therefore assigns the same frequencies to more than one operator system standard [10].

From this approach the problem arises, how to guarantee the QoS and how to apply a fair resource sharing between systems competing for the same radio resource. The problems of coexisting radio systems sharing a common spectrum have not yet been well understood, and appropriate rules for the coordination of different systems have not been investigated.

A fixed spectrum allocation of different operators leads to another form of inefficient spectrum use. If they have unequal market shares, there may be systems operating at high spectrum efficiency with short frequency reuse distances, and at the same time there may be other systems of operators having smaller market shares using the exclusive resources less efficiently.

In [10], the United States Unlicensed PCS Band is explained where an etiquette is used to allow different system types to coexist with each other. Unfortunately, approaches as Listen-Before-Talk being used in this band do not allow one terminal to *raise its hand* and to require spectrum for a certain time with higher priority. That is the point where more sophisticated sharing rules are required, as discussed in this contribution.

THE TWO SYSTEM TYPES

The key functionalities of the two system types are described in [11, 12]. The ETSI Project (BRAN) focuses on standards for different types of wireless broadband access networks. One of these systems called HiperLAN type 2 (HiperLAN/2) shall provide high-speed communications with a bit rate of up to 54 Mbit/s between mobile terminals and various broadband infrastructure networks. In the U.S., a high-speed physical layer at 5 GHz is being developed to extend IEEE 802.11, which will reuse the HiperLAN/2 MAC layer. 802.11a accepted the same OFDM transmission scheme leading to easier spectrum coexistence. The respective system in Japan will have three different protocols for three different services, but it will be based on a the same common physical layer.

The three systems in Europe, the U.S. and Japan will operate in the 5 GHz band. All three physical layers will be harmonized to a large extend. The two possible network topologies are referred to as on the one hand ”infrastructure- based”, that is, terminals communicate with the core network via a so-called access point, and on the other hand ”ad-hoc”, where terminals communicate with each other without the connectivity to the wired core network.

HiperLAN/2 is basically centrally controlled announcing the time structure at the beginning of each MAC frame. IEEE 802.11a in contrast applies CSMA/CA, which is understood as a simple listen-before-talk scheme. To support QoS and to carry real-time services, some priority schemes are optionally included (Point Coordination Function). For coexistence, two issues have to be mentioned. HiperLAN/2 allows the dynamic allocating of new frequencies (Dynamic Frequency Selection, DFS), as well as Transmitter Power Control (TPC). The IEEE 802.11a systems keep operating at one single carrier once it has been selected. Both systems apply Link Adaptation (LA), i.e. the flexible interference-dependent selection of modulation and coding.

WLANs as IEEE 802.11a and H/2 in the U.S., will work in the Unlicensed National Information Infrastructure (U-NII) band illustrated in Figure 1. In this unlicensed band, essentially every radio system is allowed to operate, provided that it does meet transmission power and spectrum efficiency requirements.

The 5 GHz U-NII band is divided into three parts

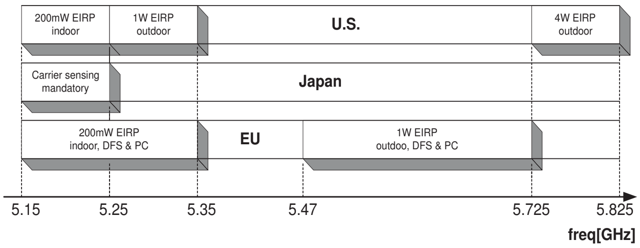

Figure 1: 300 MHz spectrum are released for the Unlicensed National Information Infrastructure at 5 GHz in the U.S. Similar bands are available in the Europe and Japan.

with different allowed EIRP (Effective Isotropically Radiated Power) values. The EIRP is calculated as the product of the transmitted power (in Watt) times the gain of the antenna (as a power ratio). Thus, the 200 mW band provides in-building operation, the 1 W band allows campus or small neighborhood services and the 4 W band will allow scenarios of up to 10 km radius, approximately.

The U-NII solution considers the location and time dependent requirements on frequencies of the radio systems and therefore assigns the same frequencies to more than one system standard.

WHY THE FAIR COEXISTENCE REQUIRES AN ETIQUETTE

The uncoordinated operation of coexisting radio systems has been started within the 5 GHz band opening 300 MHz by the FCC for the U–NII and at the frequencies of the ISM band 2.4 GHz. For the services that are offered in these frequencies no QoS is supported but a best-effort service is provided.

With the introduction of HiperLAN/2 systems as transparent wireless extension of *ATM*, *UMTS*, *IEEE 1394*, and *IP*, offering services with quality requirements known from the fixed ATM network to the end-user, and with the introduction of IEEE 802.11a, basically as wireless extension of Ethernet, means have to be found to provide the fairness and the opportunity to the individual systems to protect their active terminal during communication phases and to guarantee a certain QoS. This is obviously not an easy task as all systems are going to operate at the same frequency band.

Since future services require large bandwidths, the systems may have to use frequencies that are spread over several compounds that are free of interference. Further, to allow the new systems to share the frequencies with other new or existing systems, the new systems should possess some innovative approaches, which can make the new systems more capable to survive in the extreme situation where only a small spectrum is available.

FSRs must be defined to allow various systems to coexist. They drive the telecommunication market by allowing the different systems to work in the deregulated band. Only systems obeying a defined etiquette and, thus, applying respective FSRs, will be able to provide quality for supported services, as there will not be an exclusively reserved spectrum for any type of system. In the considered spectrum, HiperLAN/2, IEEE 802.11a, to a certain extent the Japanese MMAC, satellite communication systems and some scientific applications have to share the spectrum. All these systems operate in an unlicensed band, uncoordinated. They all individually need to be protected. As the ad-hoc and infrastructure-based systems are likely to work on their own without any synchronization to other systems which are working in the same or adjacent areas, HiperLAN/2 must be protected against HiperLAN/2, IEEE 802.11a against IEEE 802.11a, as well as both the different systems against their foreign counterparts. There is no reason to argue that if two customers both purchased HiperLAN/2 and a third one decided to use IEEE 802.11a, that the first two are interested to coexist by at the same time not allowing the third system to work simultaneously. In other words, each system will work trying to get as much resources as possible (if required by the offered traffic) where all other systems will be interpreted as competitors, having equal rights, regardless what kind of system it will be. In a conservative approach, all systems try to be as selfish as possible, leading to non-cooperative not very spectrum-efficient scenarios. FSRs will be the means to achieve cooperation among the uncoordinated systems.

SIMULATIONS

To show how severe the mutual interferences may destroy the communication of the systems, some initial simulations have been performed.

A. Scenario

Using Telelogic's specification and simulation tool SDT, a simulation environment has been built for IEEE 802.11a and HiperLAN/2. This tool allows accurate stochastic simulations of both systems. Fig. 2 shows the basic architecture of the simulator. All relevant protocols are included. Accurate traffic models and radio channels will lead to reliable simulation results [13], but are at this point of time only roughly implemented.

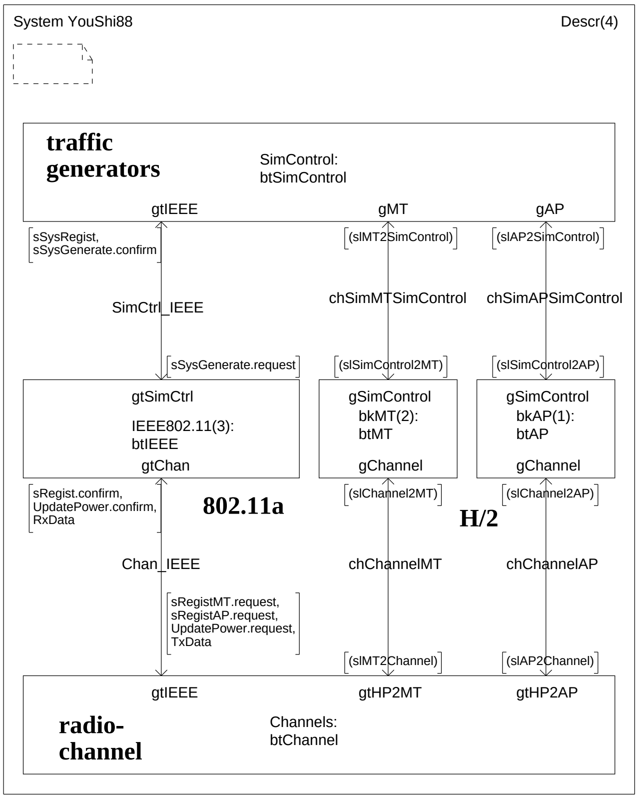

Figure 2: The simulation environment. The protocols are formally specified using SDL. As HiperLAN/2 ("H/2") is centrally controlled, two different blocks are included.

Figure 3 illustrates a simulation scenario, where two HiperLAN/2 mobile stations and one AP have to coexist with an IEEE 802.11a system including an AP and two mobile stations.

The distance between both systems is kept small. All stations are located no more than 5 m away from each other in order to simulate scenarios with harsh interference. Simple best-effort Poisson traffic is simulated. All terminals are transmitting packets with the power of 200 mW, TPC, LA, and DFS are not applied. Each of mobile stations has a duplex connection with its corresponding AP. The HiperLAN/2 system transmits all BCH-, FCH-, and RCH-PDUs with BPSK modulation with coding rate of 1/2 (i.e. 6 Mbit/s), and all SCH- and LCH-PDUs are transmitted by using 16QAM modulation method with a coding rate of 9/16 so that the transmission rate up to 27 Mbit/s is possible. The IEEE system transmits the RTS, CTS and ACK PDUs with BPSK1/2 (6 Mbit/s) and the data packets are sent with 16QAM1/2 (i.e. 24 Mbit/s). Both systems transmit their packets at the same frequency using the same carrier.

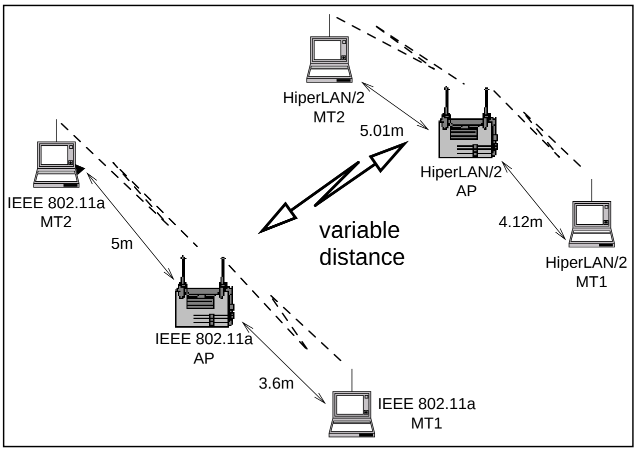

Figure 3: Typical scenario.

B. Results

Results in coexistence simulations highly depend on the scenarios. The results found in this contribution can only give a rough view on what problems may occur when FSRs are not taken into account. For example, the following two figures show the HiperLAN/2 throughput for two different configurations.

Figure 4 shows the records of two simulations. Results of a simple simulation scenario indicate the problems arising when HiperLAN/2 and 802.11a operate simultaneously without applying any sharing rule.

Both terminals have to carry the same loads of about 5 Mbit/s. Two configurations have been simulated, one in which the 802.11a is sending long packets of 1024 bytes without fragmentation (bottom) and one in which the 802.11a is sending short packets of 53 bytes, equivalent to the HiperLAN/2 LCH PDUs (top). No

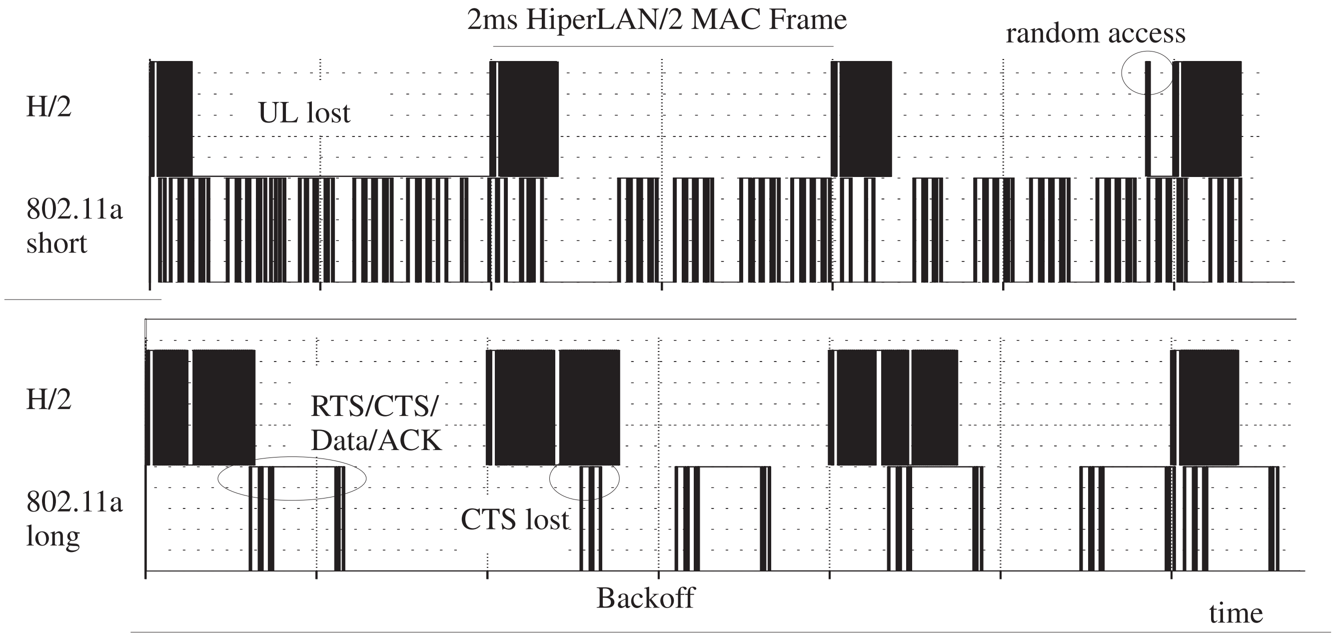

Figure 4: Simulated MAC frames with short and long data packets of IEEE 802.11a

DFS, LA, or TPC is simulated. The simulation results indicate the following: with both configurations, with small to medium load the systems do not perform well. The 802.11a packets sent after carrier sensing and after Ready To Send (RTS) and Clear To Send (CTS) bursts very often interfere with the BCH PDU of HiperLAN/2 at the beginning of the MAC frame. Once the BCH of HiperLAN/2 is corrupted, the related MAC frame gets lost and no traffic can be carried in the uplink (UL), see top figure. This is due to the fact that the BCH of HiperLAN/2 with this configuration is interfered by many 802.11a packets. Although the whole transmission period of an 802.11a packet fits into the not used parts of the HiperLAN/2 frame at least with small loads, i.e. longer periods in the HiperLAN/2 MAC frame which are not used, the BCH is very often corrupted In contrast, if the traffic load to both systems is close to its maximum (in this scenario 20 Mbit/s), i.e. the HiperLAN/2 frame is filled up well, the 802.11a system fails to operate and the HiperLAN/2 system reaches nearly its optimum. Following these preliminary results it can be concluded that without appropriate sharing rules, the mutual interferences would lead to a poor QoS for both system types.

A Technique to guarantee QoS of HiperLAN/2 interfered by IEEE 802.11a Systems

Various coordination strategies across systems as well as QoS support strategies may be followed based on TPC, LA, and DFS. One approach in HiperLAN/2 when sharing the spectrum with 802.11a is explained in this section. One method to allow real-time traffic in a shared scenario is illustrated in Figure 5.

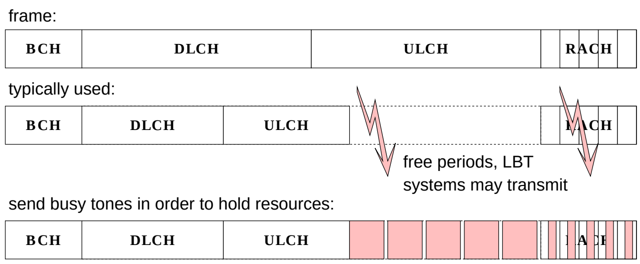

Figure 5: Resource allocation by filling the HiperLAN/2 frame

In order to avoid the transmission of a competing IEEE 802.11a terminal in not used parts of the HiperLAN/2 MAC frame, LA is applied and a modulaton and coding scheme is selected that fills up the MAC frame as much as possible. If this measure does not suffice to fill the MAC frame completely, the AP would broadcast system related management information in not used parts of the MAC frame to fill it completely and avoid a 802.11a terminal to start its own transmission. Since the random access slots of the RACH might be unused in HiperLAN/2 and could therefor allow the transmission of an 802.11a terminal, the AP will transmit negative acknowledgement (NAK) at the slots as soon as it has detect an unused random access slot. This could be performed by transmitting energy bursts after detecting that no access happened. No idle periods longer than the inter frame space necessary for starting a transmission of 802.11a (Distributed Coordination Function Inter Frame Space DIFS, 34μs) occur, and the 802.11a systems do not interfere in times when HiperLAN/2 is required to guarantee QoS for real-time traffic as voice or multimedia.

TOWARDS KNOWLEDGE BASED GAME THEORETICAL APPROACHES

Conservative Frequency Sharing Rules as currently under discussion do not take into account that at certain times some systems require more resources than the others due to the instantaneous QoS demands. For HiperLAN/2 and the IEEE 802.11a, more advanced approaches have to be defined. Derived from the mathematics of Game Theory, which are established in neoclassical economics for modeling competition scenarios, it is possible to study the competitive uncoordinated scenarios analytically. Strategies for the various systems and simple procedures for TPC, LA, and DFS will be derived. For this, analytical results will be evaluated by the simulation tool used also for the conservative FSRs.

Game Theory is a set of analytical tools designed to understand the phenomena that can be observed when competing players, i.e. decision-makers interact. The basic assumptions that underlie the theory are that decision-makers pursue well-defined exogenous objectives (they are $rational$) and take into account their knowledge or expectations of $other$ decision-makers' behavior (they reason $strategically$). That is one of the most critical issues when applying Game Theory on human decision problems such as in economics, but can be neglected in technical applications like wireless communication.

The topic of Game Theory is the investigation of strategies of individuals having contrary or conflicting interests. Hence it is also classified as "Science of Strategy". The aim is to explain existing and to predict future behavior for the design of improved strategies. Mathematical models, used to express the ideas of Game Theory formally, provide a basis on which analytical and simulative investigations are possible. Thus it is possible to verify the superiority of certain strategies over others by means of computer simulations [14]. For complete information about all possible equilibria, i.e. operating points where all systems do not require to change their strategies as they are able to carry their individual traffic, refer to [15] and [16].

The objectives in framework for future work therefore are to develop new approaches based on Game Theory for both HiperLAN/2 and IEEE 802.11a systems, and to build the accurate abstract models, including mobility, radio propagation details, and realistic traffic models, to investigate coexistence of both systems.

The models of Game Theory are abstract representations of classes of real-life situations. This abstractness allows to study a wide range of phenomena. There are already many applications of Game Theory in fixed routing problems [17] and wireless decentral radio resource control, some interesting approaches can be found in [18].

Note that it is the Dynamic Non-Cooperative Game Theory which may lead to most promising results, requiring for some sophisticated cognitive knowledge management being implemented in the communication systems. Approaches to cognitive software radio can be found in [19].

CONCLUSION AND OUTLOOK

Industry, manufacturers, standardization institutes, as well as regulatory bodies require for more research towards the understanding of FSRs. There is a considerable gain in all aspects of decentral resource sharing resulting from the discussed approaches. Major sections of the rules need to be developed in concert with industry. Therefor, the authors are going to continue to work on the set of rules and procedures for standardization of both the HiperLAN/2 and the IEEE 802.11a types. The work will disseminate the following results:

- a rationale for the rules and background scenarios to aid understanding of the new rules
- an implementation guide for the rules and strategies
- a help for regulator bodies, namely ERO, RegTP, ETSI, FCC, ARIB
- a set of conservative FSRs, based on schemes as Listen-Before-Talk
- a set of advanced coordination procedures based on Game Theory

In addition to the discussed autonomous allocation techniques, sharing rules are currently under investigation in order to find an etiquette. The etiquette will allow the spectrum efficient and fair coexistence of HiperLAN/2 and IEEE 802.11a in the U-NII and license exempt bands at 5 GHz, under consideration of QoS.

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