Spectrum Scheduling and Brokering Based on QoS Demands of Competing WISPs

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Abstract- **During the last years, several Wireless Internet Service Providers (WISPs) install Base Stations to public areas in order to offer Internet feed or voice services to users and subscribers. These Base Stations use licensed-exempt spectrum, and limited regulations apply during their deployment. Thus, the providers offering wireless services in overlapping geographical areas need interference-free, access resolution mechanisms to reserve and use wireless resources. Moreover, to offer guaranteed level of services to end users, WISPs need to cooperate in terms of quality of service (QoS) scheduling. Additionally, each WISP might apply diverse criteria to charge the offered services. These issues are addressed here, and a distributed medium access control scheme, called Distributed QoS based Dynamic Channel Reservation (D-QDCR), is proposed. D-QDCR allows Base Stations of different wireless providers to compete and reserve a carrier, based on data volumes or QoS demands, to distribute the allocated carrier, as well as time, to the associated wireless terminals and to charge the offered services accordingly.**

Keywords: Spectrum Sharing, Wireless LANs, QoS

I. RADIO LANS AND WISPS

Radio Local Area Networks (RLANs) have been proposed as cost effective and complementary infrastructures next generation cellular networks. It is anticipated that in the future these two types of networks will converge towards the Always Best Connected (ABC) context. For a Wireless Internet Service Provider (WISP) that offers commercial services, the spectrum regulation framework is critical. Since RLANs BSs use the unlicensed spectrum and limited regulations apply for their deployment, installations of different providers might coexist in public spaces. In such an environment of coexistent RLANs, spectrum usage regulations are essential, not only to avoid interference situations, but also to provide guaranteed services to end users. Such rules will protect WISPs investments, enabling the differentiation of each WISP in terms of offered services and charging. Some WISPs offer radio access for Internet users, which are interested on data volumes transfer; others deploy RLANs to serve customers' phone calls, using VoIP, which are concerned about the QoS . A typical WISP will provide both services. To charge the offered services using a charging model (e.g., subscription, data volume based), WISPs with coexistent RLANs should regulate the access to the shared spectrum. A central coordination entity that regulates the usage of the unlicensed spectrum as in [1] might be inappropriate, when coexisting BSs of private RLANs have access control limitations. Ηερε, we propose a Distributed QoS-based, Dynamic Channel Reservation (D-QDCR) method for avoiding interference phenomena and scheduling of wireless resources in RLANs. D-QDCR provides the rules, based on differentiation of the offered level of service. These rules are followed by BSs in order to regulate competition, and to facilitate wireless resource reservation. Through competition periods, each BS dynamically discovers its interferers and competes with them taking into account the QoS demands or the data volume. A winning BS reserves time on a carrier, and schedules this time to its associated Wireless Terminals (WTs). Using D-QDCR, the BSs are able to allocate the committed resources per end-user connection, charging the wireless access according to their market model. The proposed self-organized approach requires no frequency preplanning phases.

II. SCHEDULING RESOURCES IN RLANS

A. *MAC for BS-oriented RLANs*

In the 90's, various MAC schemes have been introduced to support QoS in BS-oriented, wLANs. Most of these proposals used dynamic TDMA, mainly with a variable length time frame. ETSI HIPERLAN/2 uses static TDMA/TDD [2]. Moreover, the 802.11 standards describe a system, where, if a BS is present, several operations are under its control. In its centralized version, the BS allocates time quanta to WTs (Contention Free Period, CFP). In its distributed version, the WTs use a sequence of messages to exchange information (Contention Period, CP). The CFP and the CP periods configure an 802.11 super frame that is repeated under the control of the BS. The duration of an 802.11 frame might vary, whilst CFP and CP periods might vary per frame, as well [3]. The enhanced 802.11e standard handles service classes and QoS. New mechanisms, such as Hybrid Coordinator and Enhanced Distributed Coordination Function are recommended to support different Traffic Categories. IEEE 802.11e uses the two periods within the superframes, (i.e., a CP and a CFP) [4].

B. *Spectrum Regulations*

Initially, the 2,4GHz ISM band was used for the deployment of the RLANs. In the U.S., the Unlicensed - National Informa-

[1] Part of this work was performed in the context of the project entitled "Always Best Connected Provision in Heterogeneous Mobile Networks" funded by the Greek Ministry of Education under the framework "Pythagoras".

tion Infrastructure (U-NII) systems operate using three zones of 100MHz in the 5GHz band. For the U-NII systems, the spectrum is divided in 13 carriers. In Europe, CEPT (ECC these days) has designated 19 orthogonal carriers of 20MHz in two zones for HIPELRAN/2 devices [5]. In Japan only the 5.150-5.250GHz zone is available for RLAN deployments [6]. Different type of RLANs applications uses different bands and EIRP levels (Fig. 1, [7]). A worldwide allocation framework of the 5GHz spectrum to RLANs will significantly increase the momentum of the RLAN deployment over the coming years [7]. In Europe, specific requirements are recommended to avoid occupied carriers, by employing Dynamic Frequency Selection (DFS) mechanisms, and implement Transmit Power Control (TPC) [5]. The 802.11h standard, which is under development, works to enhance the 802.11 to provide DFS and TPC. According to [5] an RLAN shall employ a DFS function to detect interference from other systems and to avoid co-channel operation with these systems, notably radar systems operating in the bands 5.250-5.350 and 5.470-5.725 GHz. ETSI recommends that DFS functions should be applied prior to use a carrier and during normal operation. Thresholds are defined, such as carrier availability check time and interference detection threshold, to avoid interference with non-RLANs. Finally, the ITU M.1652 [8] proposes the usage of a DFS to avoid interference form radiolocation and maritime radio-navigation services.

C. *Coexistent RLANs*

ITU and ETSI take into account inter-DFS etween RLANs and non-RLANs. On the other hand, interference might occur between coexistent RLANs (intra-DFS), belonging to different WISPs. Thus, beyond any proposed enhancements on the MAC layer and advanced inter-DFS mechanisms, resource-scheduling mechanisms should take into account the unlicensed operation of RLANs. Several methods suitable for interference resolution of BSs that operate in a common area have been proposed in the literature. Hettich et al. introduced a channelisation approach of the available bandwidth, where certain frequencies are assigned exclusively to each type of BSs [9]. Listen Before Talk (LBT) rules are applied for carrier reservation, whilst reservation time is limited to a maximum. An alternative approach introduces super-frames (repeated cycles of containers) in each of the available license-exempt carriers [10]. According to this scheme, the BSs reserve idle containers and control the sharing of the allocated container among their associated WTs. The performance depends on the cycle of the super-frame (i.e., number of containers per super-frame) and the duration of each container. The CSCC approach, where a special purpose carrier is suggested for access coordination was proposed in [11]. Each carrier accommodates different service types (as in [9]). The BSs execute mutually agreed spectrum sharing procedures (e.g., priority resolution), using an etiquette protocol.

III. D-QDCR Mechanism

D-QDCR applies to BSs that act as communication hubs, offering wireless access to associated WTs. Each WT maintains an association with one of the BSs, until it performs a handover. A MAC mechanism (e.g., IEEE 802.11e) is assumed to schedule uplink and downlink MPDUs based on QoS requirements, and produces variable length time frames. The available spectrum B (from X_0 MHz to X_1 MHz) is divided into M orthogonal carriers, each of a central carrier Fc, c=1,…,M. A BS can access any of the M available RF carriers, but can use only one RF carrier at a time.

A. *Burst Signals*

D-QDCR separates control from data channels. Control channels are used to resolve competitions, and to broadcast carrier status information. D-QDCR uses special signal bursts broadcast by the BSs during control channels. A signal burst is energy transmitted by BSs to indicate certain conditions and to broadcast control information. A BS broadcasts the following burst signals:

- Priority Burst Signal (PBS), during the priority resolution phase, declaring its QoS demand.
- Request Burst Signal (RBS), during the competition phase, carrying information such as perceived delays
- Periodic Priority Burst Signal (PPBS), periodically

PBS requires less than a slot for its transmission. The RBS duration is variable. PPBS is broadcast periodically, requiring one slot for transmission.

B. *D-QDCR channels*

D-QDCR operates in time frames of dynamic duration, called Q-frames. A Q-frame starts when a carrier is sensed idle by one or more BSs, and consists of several control and data channels, which allow BSs to reserve a carrier, to exchange data with associated WTs, and to broadcast control info. The Q-frame channels are: a) the Priority Resolution Channel, b) the Competition Resolution Channel, c) the MAC Channel, and d) the Periodic Priority Resolution Channel.

1) Priority Resolution Channel (PR-CH). During this phase, each BS estimates its Reservation Priority (RP), taking into account the data volume or the QoS required by the accommodated connections. Different definitions of RP can be used, according to the profile of the WISP.

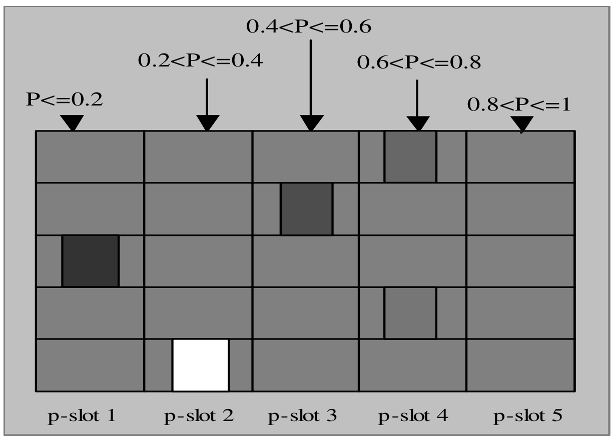
- Category 1. PAWNs that offer internet feed to subscribers or ephemeral users are interested to compete in terms of transferred load and packet loss ratios
- Category 2. PAWNs that provide telephone services or streaming video on demand are interested to compete in terms of transfer delays
- Category 3. PAWNs that offer a broad range of services are interested to compete in terms of load, transfer delays and packet loss ratios

Thus, RP can be defined using different competition criteria. We assume that at a particular time instant the r-th RLAN BS (BS_r), managed by any WISP, serves a total number of K_r connections, classified in four different sets:

- $\{C_1, \ldots, C_{K_C}\}$ with delay restrictions
- $\{V_1, \ldots, V_{K_V}\}$ with loss restrictions
- $\{R_1, \ldots, R_{K_R}\}$ with loss and delay restrictions,

Each C or R type connection introduces an upper transfer delay threshold, D_{thr}. Each V or R type connection introduces a loss threshold, L_{thr}. Three different contention disciplines are proposed here. The first one, called TLF, gives priority to BSs that serve large data traffic, and it is applicable to the BSs that belong to category 1. The second, called NJF, assigns priority to BSs that serve connections with strict delay restrictions, and it is applicable to BSs that belong to category 2. The last one, called QJF, gives priority to BSs that accommodate connections with loss and delay restrictions.

- Traffic Load First (TLF). This policy is based on the volume of MPDUs, belonging to any type of connection that each BS should serve.
- NMRL Job First (NJF). This policy is based on MPDU residual lifetimes (MRLs). When forming a MAC time frame, each BS MAC scheduler calculates the normalized MRL (NMRL), among all the accommodated connections.
- QoS Job First (QJF). This assigns balanced scheduling priorities to connections with delay or loss requirements.



Fig, 2. The structure of the PR-CH

The PR-CH period consists of a constant number of slots, which are further subdivided to a fixed number of minislots (called p-slots). Thus, if each PR-CH slot is divided to G_P p-slots, then the granularity, G, of the PR-CH period is G_S*G_P. Each p-slot position corresponds to a particular RP. For instance, assuming a $G_P=5$ p-slot granularity and a PR-CH of one slot ($G_S=1$), for the NJF or QJF disciplines the first p-slot corresponds to $RP\leq0.2$, the second p-slot corresponds to $0.2<RP\leq0.4$, and the last p-slot corresponds to $0.8<RP\leq1$, as shown in Fig. 2. For the TLF policy the first p-slot of the PR-CH period corresponds to $RP\leq10$, the second p-slot corresponds to $10<RP\leq20$, etc. According to the estimated RP, a BS will broadcast its PBS using the corresponding p-slot. The best effort service class will use the first p-slot of the PR-CH period to broadcast the corresponding PBS. If D_{PBS} is the duration of PBS, and D_{PS} is the duration of a p-slot, then $D_{PS}>D_{PBS}$, and $TAT<D_{PS}-D_{PBS}$. This allows a BS to switch from transmit to receive mode and sense PBS broadcast in the next order p-slot. A backlogged BS, i.e., one with low PR will sense the PBS burst of the BS with higher PR, because the latter will broadcast its PBS using a higher order p-slot. Backlogged BSs should select a new carrier, among the M candidates, to compete for it, using the intra-DFS method that will be discussed later.

2) Competition Resolution Channel (CR-CH). In the PR-CH two or more BS may use the same p-slot of the highest order to broadcast their PBSs, even if the RPs are different. These BSs will erroneously conclude that they are the winners of the first phase competitions, and simultaneously reserve the carrier. To overcome such collisions we introduce the CR-CH. During the CR-CH each BS, survived from the priority resolution phase, broadcasts its reservation requests (through the RBS), and realizes the reservation requests of other survivors.

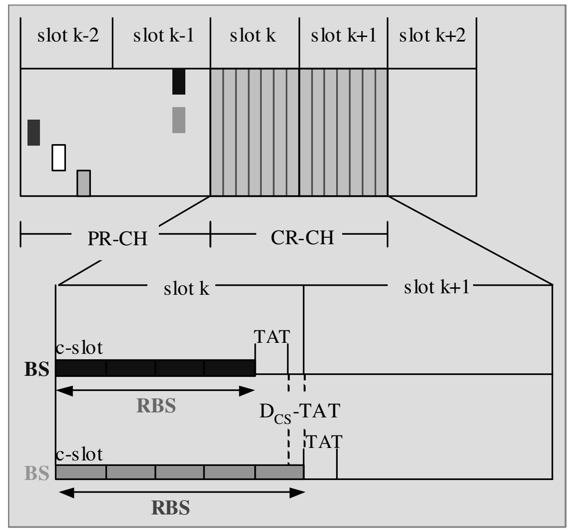


Fig. 3. The structure of the competition resolution (CR-CH) channel

The CR-CH comprises an integer, but not fixed, number of slots, each of which is subdivided into a fixed number of minislots, referred to as c-slots, as Fig. 3 illustrates. The RBS signals are transmitted in continuous c-slots, and simultaneously by the competing BSs. We introduce a granularity factor G_C, $0<G_C<1$. If the reservation request is T slots long, then RBS will use $[G_C*T]$ c-slots for its transmission. We assume that $TAT<D_{CS}$ where D_{CS} is the duration of c-slot. This allows a BS to switch from transmit to receive mode and sense RBS broadcast by other BSs. A backlogged BS, i.e., one with lower reservation request, senses the RBS burst of another BS illustrating higher reservation request, because the latter will broadcast an RBS using at least one more c-slot. Backlogged BSs select a new carrier to compete for it, using the intra-DFS function described later. The survivor is the BS that has completed its RBS transmission, switches on receive mode, and senses idle carrier. This BS will reserve the carrier, for a period equal to its time frame.

3) Medium Access Control Channel (MAC-CH). This channel is used for data transfer. It consists of the following:

- Frame Header Broadcast Channel (FHB-CH). Within this channel a BS broadcasts a map, providing information on which slot each WT can use to send or receive data.

- Down Link Data Channel (DLD-CH), with variable duration, for BS to WTs transmissions.
- Turnaround Channel (TAT-CH), which allows WTs or BSs to switch between receive and transmit modes.
- Up Link Data Channel (ULD-CH), with variable duration, for WTs to BS transmissions.

4) Frame Trailer Channel (FT-CH). This channel occupies one slot. Within this channel, the BS broadcasts to its associated WTs a visiting list of the carriers that the BS will visit sequentially until a successful reservation.

5) Periodic Priority Resolution Channel (PPR-CH). It is equivalent to PR-CH, and uses one slot, in which the BSs broadcast their RPs. Here, only the sensing BSs broadcast their priorities; the BSs that with carrier reservation do not transmit. It is used to force BSs with lower RPs to abandon a congested carrier.

6) Idle Channel (ID-CH). The maximum number of idle slots during PR-CH and CR-CH is G_S-1 and G_R-1, respectively. The minimum number of consecutive idle slots that the listening BSs should sense prior to competition is:

$$N_I = \begin{cases} G_S - 1 \ \ if\ G_S > G_R \\ G_R - 1 \ \ if\ G_R \geq G_S \\ 1\, if\ \ G_S = G_R = 1 \end{cases}$$

Fig. 4 illustrates the proposed Q-frame and its channels. Three mutually interfering BSs, which compete for a carrier, are assumed. During PR-CH, BSs 2 and 3 use the same order p-slot to broadcast their PBS, whilst BS 1 uses a lower order p-slot. BS 1 loses the competition; BSs 2 and 3 broadcast their RBS during CR-CH. BS 3 broadcasts a longer RBS, and reserves the carrier. BSs 1 and 2 change carrier according to their visiting lists. During PPR-CH, BS 4 (which starts sensing the carrier before PPR-CH) broadcasts its reservation priority, as BS 3 suspends its reservation.

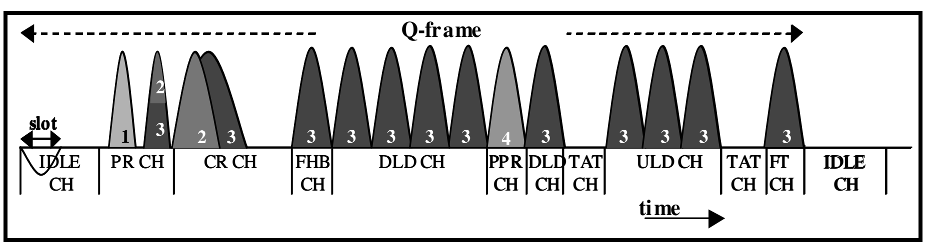


Fig. 4. The structure of the Q-frame

C. D-QDCR intra-DFS

A critical issue for the competing BSs is to select a carrier that is less congested, before starting to compete for its reservation. In [12] we have introduced an intra-DFS mechanism, called Congestion Factor Real Time Estimation (CFRTE). Its main objective is to rapidly identify a "free" carrier, among the M candidates. In [13] we have used a Linear Reward-Penalized learning automaton to predict carriers' congestion. Fig. 5 illustrates the MPDU Loss Ratio of V, R and C type of connections, due to transfer delay violations (D_{thr}, for C and R-type) and buffer overflows (L_{thr}, for V and R-type) when the TLF applies. We assume carrier selection based on a random choice (no-DFS) or the CFRTE.

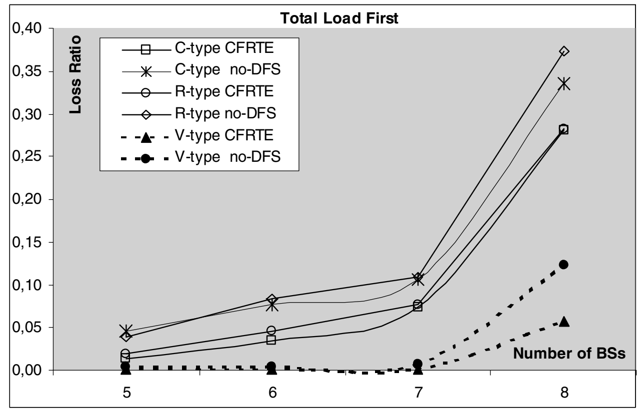


Fig. 5. Loss ratio when TLF applies

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