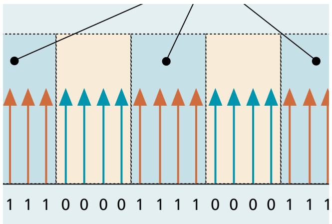


# Spectrum Pooling: An Innovative Strategy for the Enhancement of Spectrum Efficiency

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## Abstract

This article describes the technical challenges that have to be met when implementing the interesting new technology of spectrum pooling. This notion represents the coexistence of two mobile radio systems within the same frequency range. It enables the secondary utilization of already licensed frequency bands as aimed at by several regulatory authorities worldwide. The goal of spectrum pooling is to enhance spectral efficiency by overlaying a new mobile radio system on an existing one without requiring any changes to the actual licensed system. Several demanding tasks originate from this idea. Some of them have been solved in recent research projects. Others are subject to ongoing investigations. Here, the state of the art in spectrum pooling is presented.

## Introduction

The importance of ubiquitous wireless access to the Internet has been constantly growing in the last years. As wireless applications become more and more sophisticated and widely used, the demand for more bandwidth will increase substantially. In order to satisfy this growing demand one has to conceive new concepts for a more efficient way of using spectral resources. Old policies of spectrum licensing need to be rethought. This circumstance became obvious during the auction campaign for the European third-generation (3G) mobile Universal Mobile Telecommunications System (UMTS) in 2000. Furthermore, it is questionable whether the upcoming 3G systems will be able to cope with the increasing spectrum demand even with their evolved transmission techniques.

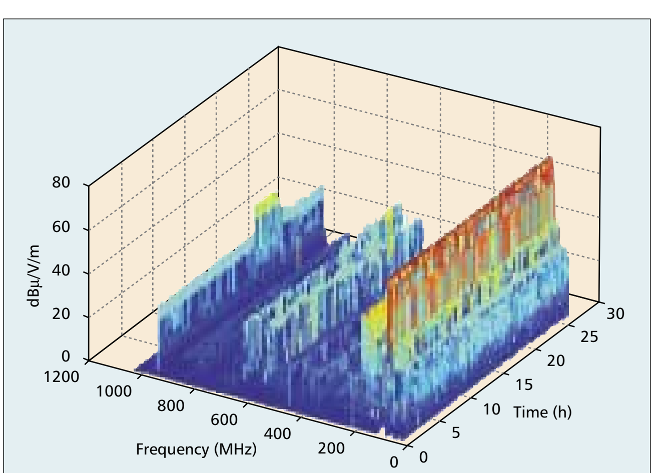


**FIGURE 1.** *Spectral utilization during one day (50 MHz–1 GHz).*

Hence, new spectral ranges that are suitable for mobile radio transmission need to be made available to the public even if they are already licensed.

Measurement campaigns in Lichtenau, Germany, in 2001 showed that large chunks of potential spectral resources are used only sporadically. Figure 1 illustrates the electromagnetic field strength observed in the 50 MHz–1 GHz range in one day. One can see constant use in the frequency bands below 300 MHz, allocated to analog audio and video broadcast. The European 2G Global System for Mobile Communications (GSM) appears as a spectral peak around 900 MHz. However, wide ranges in between show almost no spectral activity. Considering the shortage of bandwidth in public frequency bands like the industrial, scientific, and medical (ISM) bands at 2.4 GHz and 5.1 GHz, this circumstance is a waste of resources a modern society, depending more and more on the availability of mobile communications, can hardly afford.

This article discusses a new approach called *spectrum pooling* that enables public access to already licensed frequency bands. The notion spectrum pool was first mentioned in [1]. It basically represents the idea of merging spectral ranges from different spectrum owners (military, trunked radio, etc.) into a common pool. It reflects the need for a completely new way of spectrum allocation as proposed in [2, 3]. From this common spectrum pool hosted by the so-called licensed system public rental, users may temporarily rent spectral resources during idle periods of licensed users. The basic proposition is that the licensed system does *not* need to be changed. The installed hardware can be operated like there was no other system present in the same frequency range.

This approach kills two birds with one stone. Rental users obtain access to spectral ranges they have not yet been allowed to use, and the actual license owners can tap new sources of revenue for a good they have not been using intensively anyway. A multitude of juridical and economic consequences occurs when implementing the idea of spectrum pooling in a real system. Concerning the regulatory aspects of spectrum pooling, one must say that regulators are well aware of the fact that public mobile radio spectrum is falling short, and considerations toward secondary use of already licensed frequency bands are going on. After all, it is a political question whether this new concept will be admitted. However, once the technical obstacles are overcome and the feasibility of spectrum pooling is proven, politics cannot refuse this idea. The economic questions that must be answered are currently subject to scientific investigations in research projects [4] funded by the European Union involving a variety of topnotch industrial partners and leading edge research institutions.

Despite all the interesting juridical and economic aspects, this article focuses on the technical challenges spectrum pooling implies. First, a short introduction to the general structure


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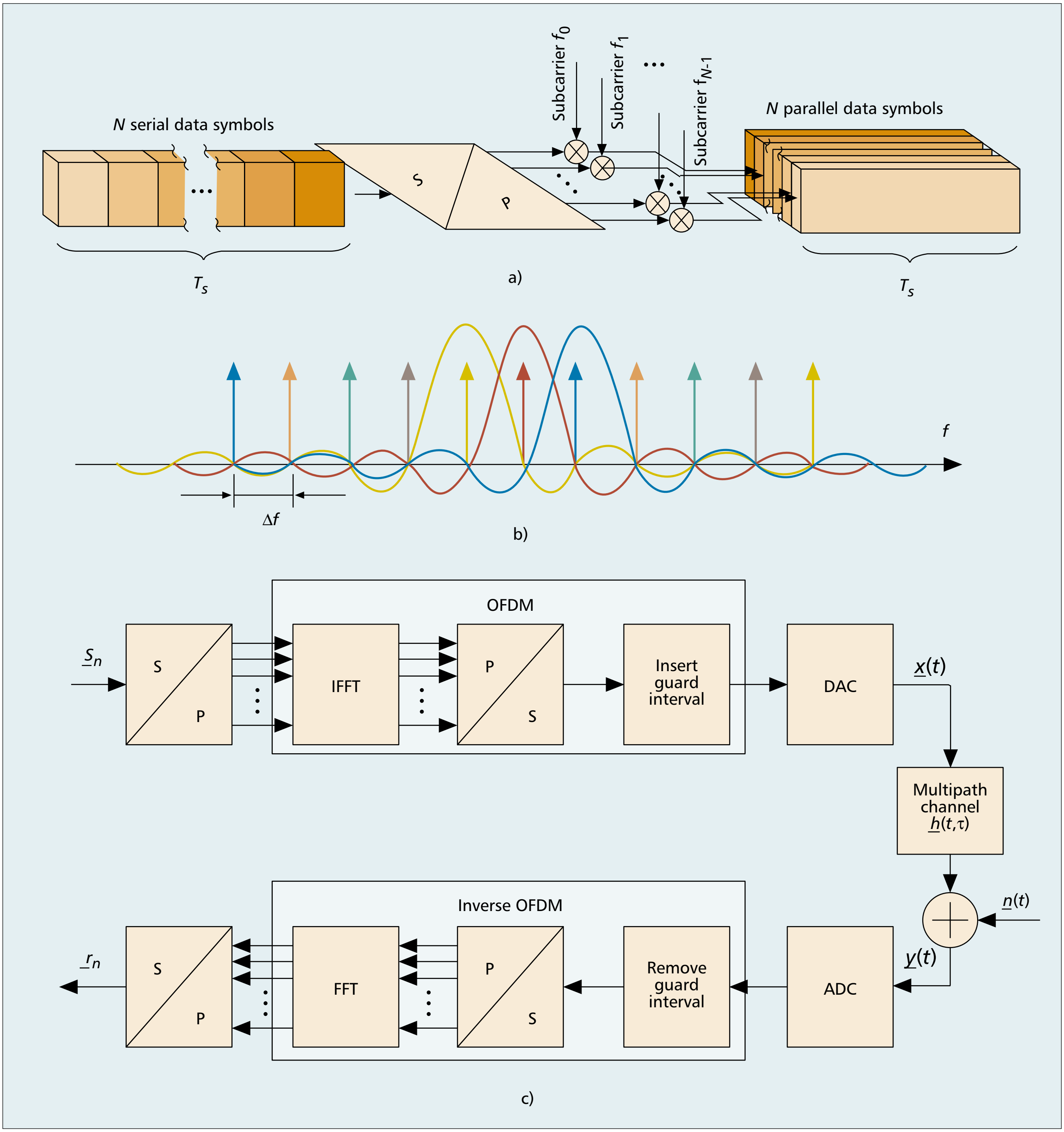


**FIGURE 2.** *a) Multicarrier transmission, b) orthogonality, and c) OFDM transceiver structure.*

of a spectrum pooling transceiver and the utilized orthogonal frequency-division multiplexing (OFDM) modulation scheme on the rental user side is given, which is essential to understanding the remainder of this article. After investigations of spectrum pooling, specific tasks in the physical layer, and problems and their solutions concerning the MAC layer of the rental system are presented. A summary will close this article.

## The Spectrum Pooling Scenario

This section describes the basic principles of a spectrum pooling system and the assumptions that have to be made regarding the licensed system. In this context, code-division multiple access (CDMA)-based licensed systems are not investigated due to the fact that the corresponding spreading codes would need to be known. This cannot always be the case, especially if one considers military licensed systems with their sensitive applications. Hence, the focus is set to frequency-/time-division multiple access (FDMA/TDMA)-based licensed systems. Investigations on specific licensed systems like GSM/General Packet Radio Services (GPRS) were conducted in [5].

A potential rental system needs to be highly flexible with respect to the spectral shape of the transmitted signal. This property is absolutely necessary in order to efficiently fill the spectral gaps the licensed users leave during their own idle

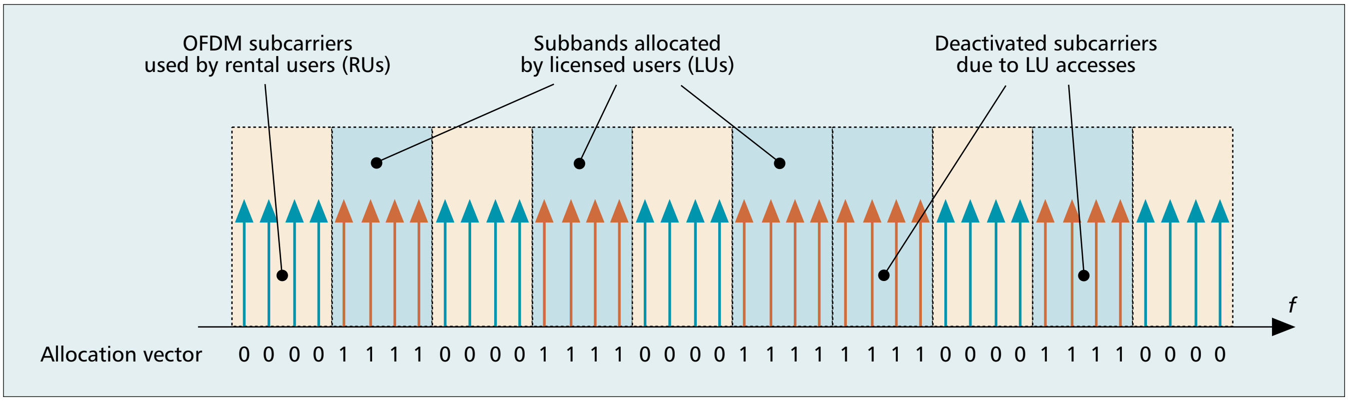


**FIGURE 3.** *A schematic example of an OFDM-based spectrum pool.*

periods. OFDM modulation is a candidate for such a flexible rental system as it is possible to leave a set of subcarriers unused providing an adaptive transmit filter. In order to fully understand the presented OFDM-based approach to spectrum pooling, a short introduction to this popular multicarrier transmission technique is given. The basic principle of OFDM is the conversion of a high-rate serial data stream to multiple parallel low-rate substreams, as depicted in Fig. 2a. For example, a set of serial data symbols is transformed into a so-called OFDM symbol representing parallel data. After serial-to-parallel conversion each substream is modulated onto a single subcarrier. The advantage of this parallelism is a decreased symbol rate on each subcarrier, which results in lower sensitivity to intersymbol interference and hence a simple equalizer structure.

Note that it is necessary in an OFDM system that the coherence time of the channel be greater than the duration of one OFDM symbol $T_S$ (i.e., the channel can be considered constant during $T_S$). Another requirement is that the coherence bandwidth of the channel be greater than the subcarrier spacing $\Delta f$. With these conditions fulfilled, an OFDM receiver design with low complexity is possible.

The orthogonality of all modulated subcarriers is maintained if the subcarrier spacing $\Delta f$ equals the reciprocal value of the OFDM symbol duration $T_S$ and rectangular pulse shaping is assumed. This relation is illustrated in Fig. 2. A major advantage of the OFDM transmission scheme is that it is possible to realize the parallel modulation using an inverse fast Fourier transform (IFFT) operation. It can be shown mathematically [6] that in the discrete domain a parallel oscillator bank as in Fig. 2a performs nothing other than a discrete Fourier synthesis. A scheme of an OFDM transmission is given in Fig. 2c.

The basic idea of OFDM-based spectrum pooling is to match the bandwidth of one subband of the licensed system with an integer multiple of the carrier spacing $\Delta f$ used in the rental system. An example where one licensed subband is resolved by a set of four subcarriers is depicted in Fig. 3. OFDM has two key advantages in a spectrum pooling context. First, a set of subcarriers represented by their corresponding IFFT inputs can be fed with zeros, thus sparing certain spectral areas from the emission of radio power. If the rental system only uses the subcarriers lying in idle subbands of the licensed system, spectral coexistence of both rental and licensed system is possible at very low mutual interference. Second, an FFT operation is required anyway in order to invert the OFDM modulation process. This FFT operation is also necessary in a spectrum pooling system for the analysis of the spectral activity of the licensed users, and it comes at no extra cost. The depicted allocation vector is a binary representation of the subcarriers that are allowed for or banned from rental system usage.

## Challenges in the Baseband

Spectrum pooling is not considered a competitor to existing and upcoming 2G and 3G mobile radio standards. It is rather meant to be a complement in hot spot areas with a high demand for bandwidth (airports, convention centers, etc.). Hence, it is straightforward to apply modified versions of OFDM-based wireless LAN standards like IEEE 802.11a or European Telecommunications Standards Institute (ETSI) HIPERLAN/2. In this section some modifications with respect to baseband processing are investigated.

### Detection of a Spectral Access

Having explained how to avoid impairment of licensed users in the frequency domain by using OFDM-based adaptive transmit filtering techniques among rental users, the next question is how to identify the idle spectral ranges (i.e., the derivation of the binary allocation vector). The reliable periodic detection of spectral access of licensed users is a very crucial task in a spectrum pooling system since reliability is directly linked to the amount of additional interference the licensed system faces when allowing secondary utilization to rental users. The mathematical derivation of reliable detection algorithms has been investigated in [7]. As this article is tutorial in nature, an exact stochastic description is not intended.

Here, just the basic outline of the derivation of the detection algorithms is given. Two basic assumptions are to be made. First, higher-layer protocols (e.g., the medium access control, MAC, layer) of the rental system must guarantee the silence of all rental users during the detection period. Thus, the only spectral power that remains in the air is that emitted by licensed users. Second, as a worst case consideration, it is assumed that there is no line of sight between the transmitting licensed user and the detecting rental user. This ensures that in a real system with a potential line of sight situation the detection result can only get better than the results derived under this worst case assumption.

With the given conditions and application of the central limit theorem, the signal received at the rental user can be modeled as a zero mean Gaussian process superimposed by an additive white Gaussian noise process originating from the background noise of the mobile radio channel, and the thermal noise of the front-end and baseband components. Hence, the statistics of the receive signal during the detection phase can be described and applied to detection algorithms derived from the Neyman-Pearson criterion. Solving their equations delivers an optimal nonlinear detector that guarantees the highest possible detection rate at a given false alarm probability. Detection guarantees on the order of 99.9 percent need to be assured to license owners. Otherwise, licensed users are not likely to be willing to share their spectrum with others.

Analytical and simulative results reveal that the mentioned hard requirements on the detection probability can only be fulfilled with a diversity approach [7]. For instance, not only one central instance of the rental system (e.g., the access point) carries out spectral measurements; all associated mobile terminals do as well. With this distributed approach the receiver operating characteristics (the detection probability as a function of the false alarm probability) can be improved dramatically, and a detection probability of 99.9 percent is obtainable at false alarm probabilities of less than 1 percent. Low false alarm probabilities are necessary in order to maintain the highest possible throughput in the rental system. A high false alarm probability would prevent idle spectral ranges of the licensed system from being used, thus diminishing the efficiency of the rental system.

## Collection and Broadcast of Spectral Measurements

One drawback of the distributed approach is the enormous amount of measurement information gathered in the mobile terminals during the detection cycle that needs to be transmitted to the access point. All the individually detected binary allocation vectors need to be collected at the access point where they have to be processed using a logical OR operation. This is because it is sufficient that only one mobile terminal detects spectral access of the licensed system in order to block the corresponding OFDM subcarriers. Thus, the maximum security for licensed users with respect to interference is obtained.

However, all the allocation vectors cannot be transmitted in ordinary data frames. The number of associated mobile terminals can easily be on the order of 100. The considered wireless LAN standards allow up to 255 mobile terminals in one cell. If this signaling overhead of more than 100 allocation vectors was transmitted serially (e.g., round-robin) in ordinary MAC layer data packets there would be very few temporal resources left for useful data transmission. Furthermore, such data transmission can become very error-prone as it is interfered with by new licensed users. These new licensed users have accessed their subbands after the last detection cycle. Hence, they could not be considered in the actual allocation vector of the rental system, causing massive interference with the corresponding OFDM carriers of the rental system.

The solution to this problem is using not the MAC layer but the physical layer for this signaling. A very elegant method to realize this is the *boosting protocol* that is engaged after all associated mobile terminals have finished their spectral detections. Here, only the basic principles can be described; please refer to [8] for more details. The boosting protocol is divided into two phases. The first phase deals with the signaling of the subbands newly allocated by licensed users; the second phase signals the deallocated subbands (i.e., those that have become idle again).

During the first phase of the boosting protocol, all the mobile terminals modulate a complex symbol at maximum power on those OFDM subcarriers representing the subbands newly allocated by the licensed system. All other OFDM subcarriers are modulated with no signal at all and thus remain silent. If this is carried out simultaneously by all participating mobile terminals, the access point receives a superposition of the original transmit signals of the licensed users and the OFDM signals of the mobile terminals of the rental system. This results in power amplification of the newly allocated subbands that enables extremely high detection probabilities at the access point. As this power amplification is not phase correct, it represents an interference to the licensed system; but simulation results have shown that only 10 μs *boosting* is enough to achieve reliable distributed detection at the access point [8]. Plus, only *new* accesses of licensed users are affected. Once detected, a licensed user remains spared from the interference of the boosting protocol due to its differential character.

The enormous advantage is that this procedure only takes

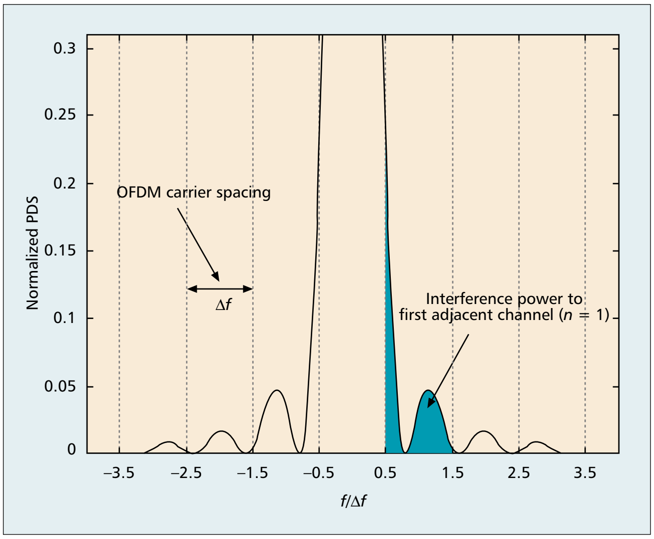


**FIGURE 4.** *PDS of a single OFDM modulated carrier in IEEE802.11a.*

a few microseconds compared to several milliseconds for conventional MAC layer signaling of measurement data as provided by the legacy wireless LAN standards. The second phase of the boosting protocol, dealing with the signaling of the deallocated licensed users, is a little more complex than the first one; the interested reader is referred to [8], where some further methods are presented concerning the robust broadcast of the allocation vector back to the mobile terminals.

### Mutual Interference

Although Fig. 3 suggests perfect spectral resolution of licensed system subbands by rental system subcarriers, this is not the case if one takes a more thorough look. In a real OFDM-based spectrum pooling system problems arise from the IFFT/FFT operation resulting in additional interference from the rental system to the licensed system *and* vice versa.

In order to understand the interference caused by the rental system one has to look at the actual power density spectrum (PDS) of the OFDM transmit signal. Using the IFFT transmitter implementation, the temporal pulse shape of one symbol is rectangular, resulting in a sinc-shaped Fourier transform of the signals on each subcarrier. In real OFDM systems cyclic prefixes become necessary. These are cyclic extensions of the transmit signal in the time domain in order to overcome intersymbol interference in a multipath radio channel. This temporal extension of one OFDM symbol results in a narrower spectrum of the signals on each subcarrier. This effect can be seen in Fig. 4 where a cyclic prefix of 25 percent of the original symbol duration was assumed. This complies with the considered wireless LAN standards.

The gray area in Fig. 4 represents the power emitted from one rectangularly modulated subcarrier into the spectral range of the adjacent subcarrier. In a pure OFDM system this power does not cause any interference to the adjacent subcarriers as their signals are orthogonal and can be separated in the OFDM receiver. In general, one cannot assume that a potential licensed system is OFDM-based. Even if it is, it would have to use the same subcarrier spacing and need to be synchronized with the rental system, which contradicts the assumptions on spectrum pooling mentioned above. Hence, the signals of the licensed users are not orthogonal to the signal of the rental system. Thus, the sidelobes of the sinc-shaped spectra on each subcarrier fully interfere with the licensed users. In bad cases the mean interference power one licensed user encounters from the rental system can be as large as 5 percent of the power transmitted on one subcarrier.

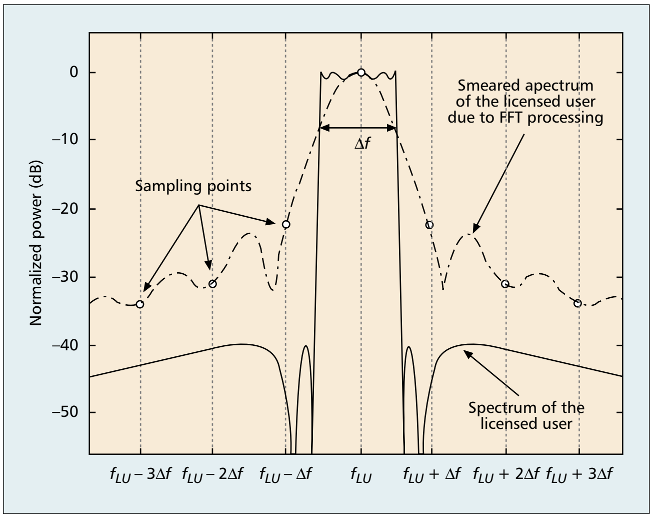


**FIGURE 5.** *The impact of FFT processing on the PDS of the licensed user.*

The interference the licensed system causes to the rental system originates from the FFT structure of the OFDM receiver. This FFT operation is performed periodically on sets of time samples. In other words, the receive signal is windowed in the time domain before it is fed to the Fourier transform. This multiplication with a rectangular window in the time domain corresponds to the convolution of the Fourier transforms of the original unwindowed signal and the window function. Hence, the original Fourier transform is smeared by a convolution with a sinc function. This has no impact on incoming OFDM signals as they remain orthogonal after the convolution. However, if a non-OFDM signal from a licensed user is fed into the OFDM receiver, the smearing effect occurs, as seen in Fig. 5. Fortunately, the interference level of this effect is only on the order of –20 dB if the same mean transmit powers of the licensed and rental systems are applied.

One measure for the mitigation of this mutual interference is the introduction of adaptive guard bands in the rental system. This implies the additional deactivation of one or more subcarriers lying adjacent to allocated subbands of the licensed system. Unfortunately, this sacrifices bandwidth in the rental system. Hence, a trade-off needs to be found between the reduction of interference power and the remaining bandwidth of the rental system. After all, this will depend on the demands of the license owners in the spectrum pool. Another interesting way to reduce the interference power to the licensed system is the use of time domain windowing techniques for the OFDM symbols of the rental system. The introduction of root raised cosine windows sharpens the spectral pulses on each subcarrier and lowers the sidelobes, resulting in less interference power. Unfortunately, this can only be carried out at the expense of a longer symbol duration, which also reduces the remaining bandwidth in the rental system.

### Synchronization

Another important baseband function of the rental system severely affected by special spectrum pooling conditions is synchronization in time and frequency. The synchronization techniques provided by legacy wireless LANs cannot be applied as the proposed preambles do not cope with the massive narrowband interference licensed users introduce when accessing their subbands.

However, exact synchronization is very important in an OFDM system as it is highly sensitive to frequency offsets, phase noise, and timing errors. All this yields a gradual loss of orthogonality of the OFDM signal, which results in substantial intercarrier interference. Most synchronization methods are based on continuous correlation of known data symbols (preambles, pilots) with either stored or delayed versions of themselves. Peaks in these correlations can be used, say, to determine the frame start, but also serve as frequency offset correctors if the phase of the correlator output is considered as well.

In [9] preambles have been investigated based on a much higher correlation length than in the original wireless LAN standards. Simulations have shown that these longer preambles can obtain a ratio of correctly detected frame starts of more than 80 percent even if half of all OFDM subcarriers are occupied by the spectral access of the licensed system. Unfortunately, the duration of these preambles is about one order of magnitude higher than the original one, and as the activity of the licensed users rises, the frame start detection probability drops sharply.

If the frame start detection ratio needs to be improved even further, one has to filter the narrowband interferers (licensed users) adaptively. This adaptive filtering can be carried out easily with the existing FFT/IFFT operation in the OFDM transceiver combined with knowledge of the allocation vector. It should be conducted in the transmitter as well as in the receiver. This method has two major advantages: the licensed users are not disturbed in their allocated subbands, and the massive interference they cause can be suppressed before the preamble is fed into the correlator. Of course, the correlation quality degrades as more and more useful spectral parts are cut out. However, simulations [9] have shown that this method enables frame start detection ratios of more than 95 percent even if 75 percent of all OFDM subcarriers are allocated by the licensed system, and at moderate preamble durations compared to the method without adaptive filtering mentioned above.

In [9] it is shown that the described adaptive filtering technique also performs very well for frequency synchronization. The standard deviation of the frequency offset can be kept to less than 1 percent of the carrier spacing, which is accurate enough to maintain the orthogonality of the OFDM signals. One drawback of this approach is that the allocation vector needs to be known in the mobile terminal. This knowledge is not available to a mobile terminal entering the spectrum pooling system. Hence, in reasonable time intervals (e.g., every 100 ms) data packets containing the allocation vector need to be transmitted using a preamble without the use of adaptive filtering techniques. Of course, this introduces additional interference to the licensed system, but it can be neglected because the duration of this interference (approx. 50 μs) is very small compared to the considered time intervals of 100 ms.

## Challenges in the MAC Layer

The impact of the licensed system on the physical layer of the rental system is quite obvious. Licensed users can be represented by a multitude of stochastic narrowband interferers. After the detection stage, their influence is reduced to a binary allocation vector. For the MAC layer of the rental system, even the exact constellation of the licensed users does not need to be known. Only the total number of subcarriers that are still available for useful data transmission is enough for tasks like frame composition, radio resource management, and handoff initiations. If one wants to investigate these functions in a spectrum pooling context, a model is needed for the stochastic properties of the number of available subcarriers (i.e., the available bandwidth).

### A Model of the Licensed User

As the potential licensed system cannot always be known in detail, some general assumptions are made. Some models based on Markov chains were already investigated in [10]. The

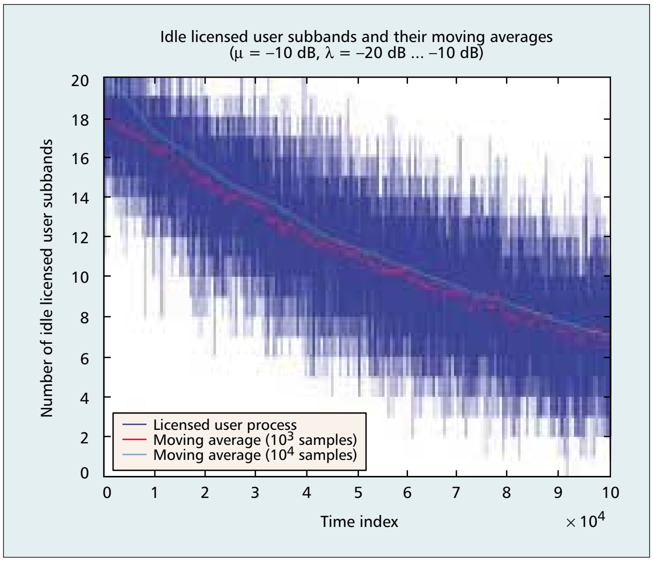


**FIGURE 6.** *Pool allocation as a random process.*

arrival process of a licensed user's voice or data transmission is assumed to be a Poisson process, which is well known from computer networks. A Poisson process is generally used to model the arrivals of data packets in packet-oriented data networks. The arrival process is memoryless: the arrival of a packet is independent of the arrival of previous and future packets. The interarrival time is exponentially distributed and characterized by the mean arrival rate $\lambda$ [11].

Once a licensed user has accessed a subband his/her occupation duration can be modeled as an exponentially distributed random variable, which is appropriate for voice applications. However, one can also apply the Pareto distribution if packet data transmission is to be modeled. The reciprocal value of the mean occupation duration in one subband is defined as the so-called service rate $\mu$ which is assumed to be a constant value for a given licensed system, whereas the arrival rate of the Poisson process is time-variant. This is straightforward if one thinks of police and fire department applications. The arrival rate will rise significantly in case of an emergency. There will always be a specific load curve for a given licensed system. The next assumption is that all these Poisson processes with exponentially or Pareto distributed access durations are independent of each other.

With all these assumptions one can simulate this array of Poisson processes and count the subbands that are not being accessed by licensed users. The sum of all these subbands yields the bandwidth available to the rental system. A realization of this "cumulative" Poisson process is illustrated in Fig. 6 for 20 licensed system subbands. Note that all time and rate values are normalized to the duration of the detection cycle in the physical layer, which can be interpreted as a sampling time for the bandwidth process as the physical layer delivers one sample at each detection cycle. The normalized service rate was 0.1; the mean occupation time is 10 detection cycles. The normalized arrival rate was varied linearly from 0.01 to 0.1 over the considered time interval, which represented rising activity of the licensed users (e.g., due to an emergency).

One can see short-term and long-term behavior of this process similar to those of a multipath mobile radio channel. The short-term characteristics are dominated by fast and heavy fluctuations of the independent Poisson processes, while the long-term characteristics originate from the slowly changing arrival rate of licensed users. From this interesting observation many consequences for the functions of the MAC layer arise.

## Handoff Algorithms

The first considered MAC layer function is motivated by analogy to the properties of the mobile radio channel where one also faces short- and long-term process components. The first is caused by constructive and destructive superposition of electromagnetic wave fronts, while the latter is caused by diffraction, shadowing, and path loss. If one looks at the receive power level of a mobile terminal moving out of the range of the access point, the curve will look pretty much the same as in Fig. 6. Once the receive power level drops below a critical value, the data transmission is disturbed severely or the connection is even interrupted.

This situation is the same in a spectrum pooling system. If the available bandwidth drops below a certain threshold, transmission of useful data is no longer possible, and all resources are used for the necessary signaling overhead, as described in the last section. The existing data connections run the risk of breaking down, which should be avoided by an early interpool handoff. This is a new form of handoff not existing in conventional mobile radio systems. It basically describes the necessity to change to a new pool with more resources left in case the current pool gets too crowded by licensed users.

Although the physical phenomenon behind the handoff initiation is completely different from classical handoff scenarios, similar algorithms need to be applied. In order to avoid ping-pong behavior between two pools, hysteresis loops need to be introduced; that is, the available bandwidth in the new pool has to be higher than that in the current pool plus a given hysteresis value. If the rental system always changed to the pool with the highest available bandwidth, there would be situations in which the rental system would have to switch pools too often, causing high signaling traffic in the backbone network and risking the interruption of the connections.

Another issue is that a handoff may not be triggered by short-term statistics. For example, if a deep fade is caused by fast fading, no handoff need be initiated as it is very likely that the channel recovers immediately from its deep fade. This reduced sensitivity to short-term statistics is realized by special filters like moving average filters in the simplest case. In Fig. 6 one can see these averaged processes at two different filter lengths. The filtered processes do not show the high volatility of the unfiltered process. The optimization of these filters as well as the optimal hystheresis characteristics with respect to throughput and interuption probability of the rental system are subjects of current research efforts.

## Scheduling Algorithms

Another MAC layer function affected by spectrum pooling concerns quality of service. Schedulers are necessary in order to distribute the available bandwidth among the associated mobile terminals and the access point. They fulfill this task according to special wireless scheduling algorithms that take into account different kinds of traffic classes. Higher-priority classes like video streams must be preferred over lower-priority classes like mail or file transfer applications.

Quality of service is a hot topic for wireless LANs at the moment. While HIPERLAN/2 already features a multitude of functions concerning quality of service, IEEE P802.11 Task Group E is currently working on the 802.11e standard [12]. Looking at the drafts reveals that the basic mechanisms will be the same as in HIPERLAN/2. There will be functions for mobile terminals to deliver their requests for resources to a central controller like the access point that hosts the scheduler. Once all the resource requests are collected, a decision must be made on which mobile terminals get what portion of the available resources. This scheduling algorithm is not standardized in HIPERLAN/2, and it is very unlikely that the final version of the IEEE 802.11e standard will contain a mandatory algorithm.

There are several scheduling algorithms known in the literature that are especially suitable for wireless applications. However, none of them has ever been tested in the special environment of a spectrum pooling system. The strong fluctuations of the available bandwidth might have a substantial impact on the performance of scheduling algorithms, especially those with memory. Current research deals with testing and tuning these algorithms in our HIPERLAN/2 spectrum pooling testbed.

## Conclusions

Spectrum pooling is a very interesting concept that enables secondary utilization of already licensed frequency bands without sacrificing the transmission quality of the actual license owner or requiring any new hardware in the original licensed system. Rental users could get access to new spectral ranges in hotspot areas where conventional public mobile radio systems run out of resources. In order to realize this challenging concept multiple problems have to be solved. Solutions to many technical aspects have been outlined in this article ranging from baseband to MAC layer issues. The main point of this article is that spectrum pooling seems to be feasible from a technical perspective. The future will show whether this idea will also be accepted by the international regulatory authorities and legislators. Of course, economic success will also depend on a serious business plan and strong marketing strategy. Hence, a lot of work remains to be done in this field, but one thing is sure: the better the technical concept, the greater the potential acceptance of legislators, regulators, and future customers.

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potentially cognitive radio as means of further enhancing the use of radio spectrum. At present there are not sufficient articles for a Supplement on aware, adaptive, and cognitive radio, but if you are working in any of those areas, your article could be the one that makes the difference between a supplement with a cognitive radio theme and just an article or two on that topic.

Finally, I would like to introduce our editorial board for the supplement. Professor Friedrich Jondral of Karlsruhe University, Germany, assisted in the creation of this initial issue in many ways, not the least of which was his collaboration with Timo Weiss on OFDM for pooled spectrum. Professor Jondral is widely known in the European Community, in the United States, and around the world for his texts on software radio and his group's research in parameterizable waveforms, among other things. Professor Ryuji Kohno took the initiative on UWB and will lead the next issue. Professor Kohno is also well known in Japan, Asia, and around the world for smart antennas, MIMO, and his broad leadership in developing SDR technology in Japan. Walter Tuttlebee has also graciously agreed to spare a few moments from his work at Mobile VCE to assist us with viewpoints from the global network of companies from the commercial mobile industry that constitutes Mobile VCE. Walter's three texts in the Wiley SDR book series and his tireless work in the field uniquely qualify him for a lead role on this editorial board. Zoran Zvonar co-edited the series on Software and DSP in Radio that preceded this Supplement, and without Zoran, there would not have been more than one of those feature topics in that series. Zoran joins Kohno, Jondral, and myself as the initial editorial board of the Supplement. We also have a number of peer reviewers and mentors to thank, but we will save that for future issues as the editorial board further takes shape in the coming months.

*Best regards*
*Dr. Joseph Mitola III*
*Area Editor*
*Radio Communications Supplement*