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COGNITIVE LTE-A SYSTEMS

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We consider the application of cognitive radio technology in future LTE-A systems. The carrier aggregation (CA) features of LTE-A can be exploited for enabling a cognitive operation in a subset of component carriers. Spectrum sharing between different network operators, device-to-device communications and the use of unlicensed bands for LTE-A are potential applications for such an operation. Sensing is expected to play an important role in such systems. To this end we explore the possibilities of spectrum sensing, especially the sensing while receiving a desired signal, in LTE-A systems. The results are expected to play an important role in the development of protocols for cognitive operation in LTE-A systems.

КОГНИТИВНЫЕ LTE-A СИСТЕМЫ

В статье рассматривается применение когнитивной радио технологии в будущих LTE-A системах. Свойства объединения несущих в LTE-A могут быть использованы для обеспечения когнитивного функционирования на подмножестве поднесущих. Распределение спектра между различными операторами сети, связь типа устройство-устройство, а также использование нелицензированных полос пропускания для LTE-A являются возможными сферами применения таких систем. Ожидается, что распознавание сыграет важную роль в таких системах. Для этого мы исследуем возможности спектрального распознавания, в особенности распознавания во время приема полезного сигнала в LTE-A системах. Ожидается, что полученные результаты сыграют ключевую роль в развитии протоколов для когнитивного функционирования в LTE-A системах.

The scarcity of spectrum and the rapidly increasing data rate demand on cellular communication systems have driven the development of the latest cellular system standards with enhanced spectral efficiency air interfaces as well as a shift towards heterogeneous networks [1][2]. At the same time, cellular operators are interested in finding ways to reduce the spectrum and infrastructure costs. In this regard, network sharing between operators [3][4], offloading of cellular traffic using WiFi in unlicensed bands etc. [5] have attracted interest. New approaches and business models are being investigated to meet these important challenges faced by future cellular systems. One of the approaches being considered is the use of cognitive radio (CR) techniques for cellular systems.

The idea of cognitive radio was proposed to opportunistically exploit the unused spectral resources in a traditional system with fixed spectrum allocation [6][7]. In such systems, the secondary users must decide on whether to transmit on a spectral resource or not. The most important requirement is to keep the interference to the primary users below a certain acceptable level. A cognitive radio system accomplishes this task by sensing the primary users' activity using the signal received at the secondary user or by querying the spectral occupancy information from a database containing information about the primary users' activity. A combination of both methods can also be considered. Due to the paramount importance of sensing for a CR system, it has been the focus of a vast amount of work in the literature. The majority of prior studies addresses the problem of sensing before transmission where the objective is to determine whether a primary signal is present or not [11], which we refer to as Type 1 sensing in this work. Recent studies have been considering a new type of sensing where the sensing is performed while the transmission of the secondary user takes place [8], which we refer to as Type 2 sensing. Traditional cognitive radio protocols consist of a sensing phase with Type 1 sensing followed by the data transmission phase. Type 2 sensing can reduce the time required for the sensing phase and increase the data transmission time, thereby further improving the spectrum utilization and the quality of service (QoS) of the CR user [12]. Hence, it is important to study the possibilities for such sensing in cognitive LTE-A systems. We explore different scenarios of cognitive operation in LTE-A systems. It is argued that the cross-carrier scheduling feature of LTE-A systems with carrier aggregation (CA) can be highly beneficial for cognitive spectrum sharing. Subsequently, we focus on energy detection algorithms for Type 2 sensing in LTE-A.

Energy detection is one of the most important methods covered in the sensing literature [13] and appealing due to its low computational complexity. The main drawback is its sensitivity to noise variance uncertainties. Nevertheless, energy detection is still attractive for practical implementations due to its simplicity. We have developed beamforming based energy detection (ED-BF) algorithms for Type 2 sensing in cognitive LTE-A systems, and the performance of the proposed schemes has been compared to that of the optimum but much more complex likelihood ratio test (LRT) algorithm under practical channel conditions and with realistic channel estimation.

Main part. In the following, we study scenarios for cognitive operation in LTE-A in more detail. Cognitive spectrum sharing becomes particularly interesting in the context of carrier aggregation (CA) in LTE-A systems. Using CA an operator can aggregate up to 5 component carriers of 20 MHz each. This creates opportunities to dynamically share a few of the component carriers. Those services with strict QoS requirements could be delivered through the unshared component carriers while services with lower QoS requirements are suitable candidates for cognitive operation. In the following, we identify scenarios for LTE-A which can benefit from a cognitive approach and discuss the various implications.

Physical downlink shared channel (PDSCH) sharing between operators

Spectrum acquisition being highly capital intensive to an operator, the increased capacity provided by CA is beneficial only if there is a sufficient demand of the users. Depending on the load, an operator could possibly use one or more component carriers in a spectrum shared manner together with another operator. The operators involved are expected to make suitable agreements on spectrum pricing, interference limits etc. In [9], we discussed the possibility of long-term spectrum sharing and short-term spectrum sharing, respectively. Long-term sharing refers to the case where sharing is applied only in the time domain and the transmission phase is of the order of several thousands of radio frames. Here, it will be possible to completely turn off the base stations as the time scales are large. In the more challenging short-term sharing, spectrum is shared in units of physical resource blocks (PRBs) in LTE. Switching the base stations on and off in such small time intervals may not be feasible. When the base station is on, it must also transmit signals such as common reference signals (CRSs), synchronization signals etc. even though the PDSCH resource elements of the PRBs are free. Thus, for short-term spectrum sharing, sensing and sharing must be performed exclusively on the PDSCH resource element positions in the PRBs of the other base station which necessitates time-frequency synchronization of the participating base stations.

Another important problem that arises from the shared operation is the collision of the control channels. In LTE, the control channels are transmitted across the resource elements of the first three OFDM symbols of a subframe. Transmitting control channels by both operators on the shared carrier would inevitably result in control channel collisions which adversely affect the control channel coverage. However, this problem can be avoided by using the cross-carrier scheduling feature in CA where data channels in one component carrier can be scheduled via control channels of another component carrier. If one of the operators has another exclusive component carrier, transmitting its control channels via this carrier avoids the control channel collisions. PDSCHs which are frequency domain scheduled and enjoy the benefits of the hybrid automatic repeat request (HARQ) technique are well suited for a spectrum shared operation. Thus, in principle, such a shared operation can be supported in LTE-A.

Inband cognitive device-to-device (D2D) communication

Inband D2D communication is an area which has attracted significant research interest recently. There are several use cases where D2D communication is beneficial and can result in higher spectral efficiency, energy efficiency, cellular traffic offloading etc. [10]. Here, the main challenge is the management of interference caused to a cellular communication. The D2D communication scenario is closely related to cognitive radio systems except that it can benefit from additional cellular supervision. It can be easily recognized that sensing capability would be beneficial in the D2D context.

LTE-A in unlicensed spectrum

LTE-A in unlicensed bands is being considered for providing higher network capacity by allowing LTE-A small cells to exploit the white spaces in the unlicensed spectrum, particularly in the 5 GHz band. Harmonious coexistence with existing WiFi networks is considered to be extremely important. Sensing issues related to LTE-A unlicensed operation are targeted for LTE-A Rel. 13. Unlike D2D communication and PDSCH sharing, this is a scenario with asynchronous interference between two different systems and hence interference will not be limited to PDSCH resource elements alone. This means that Type 2 sensing can also exploit OFDM symbols reserved for control channels. Since the control channel can be provided over the licensed carrier, in the unlicensed carrier, it will be possible to turn off the control channel transmission in the first three OFDM symbols of a subframe. In that case, control channel symbols present itself as useful sensing positions and can be directly used for Type 1 sensing over the whole band (additional CRS cancellation might be needed if CRS is transmitted in those symbols).

In the following, some considerations on Type 2 sensing based on beamforming are presented. Our energy detector with beamforming exploits the multiple antennas at the receiver to enhance the sensing performance..In [8], we studied beamformers for maximizing the probability of detection for a constant target probability of false alarm in a frequency-nonselective fading channel. It was shown that the best of the considered suboptimal beamformers is the solution to a maximum Rayleigh quotient problem. However, this approach requires knowledge of the channel of the interfering cell. This channel knowledge can be obtained with sufficient accuracy only in cases where the interfering base station is relatively close by and its reference signals are known at the sensing device. For LTE-A unlicensed operation, this is out of the scope as the interference is generated by a completely different system. With serving cell channel knowledge alone, the best approach is to choose the beamformer that minimizes the serving cell signal energy. In LTE-A, the number of spatial multiplexing streams transmitted is known as the number of transmission layers or the transmission rank. If the number of receive antennas is greater than the number of transmission layers, ED-BF transforms the sensing to a Type 1 sensing problem by spatial suppression. Detailed performance results will be discussed in the presentation.

Conclusions. In this work, we have explored various possibilities for cognitive spectrum sharing for future LTE-A systems. The carrier aggregation feature available in LTE-A can be made use of in a cognitive operation to ensure that the control channel coverage and QoS critical applications are not affected. It is shown that different possibilities exist for LTE-A that can provide reasonable sensing performance for a wide range of conditions. Specifically, we studied energy detectors based on beamforming. It is to be noted that the proposed algorithms can also be applied for an asynchronous spectrum sharing scenario with another non-LTE-A system. The study presented here is expected to be useful for the further standardization of LTE-A aimed at cognitive scenarios.

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