Guard Bands for Coexistence of UMTS and DVB in a Hybrid Radio System

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ABSTRACT

In the DRiVE project, a flexible, hybrid communication system has been developed which performs dynamic allocation of spectral resources from a common region of spectrum to the participating radio systems. Thus, new spectral neighborhoods emerge, which pose requirements regarding the protection of one system from the adjacent channel interference generated by the other system. As an example, DRiVE has focused on a hybrid system consisting of digital TV broadcast (DVB-T) and UMTS. The resulting spectral neighborhood of powerful DVB-T transmitters and UMTS requires guard bands between the dynamically assigned spectral regions, and thus decreases the overall spectral efficiency of the hybrid radio system.

This paper presents the results of simulative studies on the required size of the guard band in order to provide sufficient QoS in the participating systems. Additionally, the importance on the implementation-dependent transmitter and receiver quality is examined, taking into account laboratory measurement of available DVB transmitters and receivers. It is shown that while worst case requirements on DVB transmitter out of band performance set forth in the relevant standard can lead to poor system performance in some scenarios, state-of-the art equipment can easily exceed those requirements, and suitable allocation of channels can further improve the system performance, thus leading to satisfactory coexisting operation of UMTS and DVB-T, with only a small loss of spectral efficiency due to guard bands.

I. OVERVIEW

Given the well known constraints of high cost and limited availability of radio spectrum, efficient spectrum usage is key to the economic success of third generation cellular systems. The DRiVE IST project presented the novel concept of using available resources more efficiently by combining existing radio systems into a coordinated, hybrid system, in order to attain maximum flexibility in using available resources. The DRiVE system offers the user an integrated transport system which can adapt to both per-session QoS demands and overall system load status by dynamically choosing the most suitable RAN for the request, and by dynamically allocating spectral resources to the participating systems (Dynamic Spectrum Allocation, DSA) [10],[11].

In the hybrid system outlined above, due to DSA, DVB-T and UMTS can be spectral neighbors, and therefore any out-of-band energy emitted by one system will interfere with the adjacent system. Figure 1 shows such an Adjacent Channel Interference (ACI) scenario. The transmitter (TX) masks are defined in the relevant standards for DVB-T and UMTS [1][2][3]. However, the receiver filters (RX) are not standardized, and are here assumed to be ideal rect.

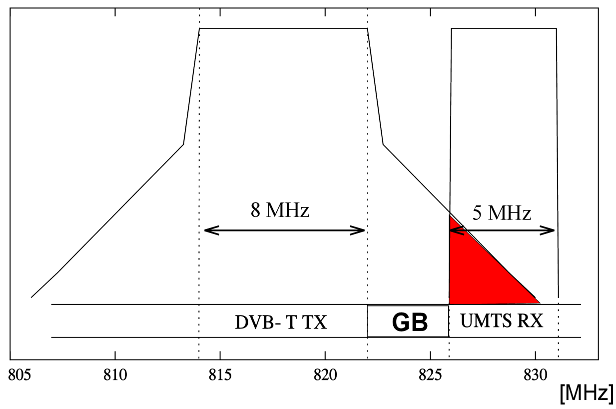

Figure 1: Interference due to mask overlap

ACI degrades the Signal to Noise Ratio (*C/I*) in the victim system, and therefore potentially decreases system capacity and Grade of Service (*GoS*) in the victim system. Therefore, guard bands (*GB*) are used between the spectral regions assigned to the interfering systems. In this context, GB is assumed to be the gap between the upper spectral border in the channel raster of one system, and the lower spectral border of the second system's channel raster.

Since Guard Bands are unusable in either of the neighboring systems, they degrade overall spectral efficiency. Knowledge of the required guard bands is therefore necessary to estimate the benefit of a DRiVE system over traditional, fixed spectrum system concepts.

Simulations were performed with a tool [9],[5] developed at the Chair for Communication Networks. The simulation tool provides a platform for multi-cellular, multi-system operation, with full support for mobility, freely configurable cell layout, and support for handover, different power-control algorithms, and flexible load generation for both packet and circuit switched traffic.

Since the focus of DRiVE is on vehicular, high speed mobility, a typical highway scenario has been chosen. Path loss is assumed to be governed by an Okumura-

Hata suburban model. Channel and mobility modeling are done with a temporal resolution of 10ms. Based on transmitter masks and receiver filters according to the relevant standards, interference levels are calculated.

Traffic generation is performed according to a configurable mix between circuit switched voice connections as a base load in the UMTS system, and packet switched data sessions, whose application layer traffic characteristic can be configured to match different types of internet traffic (HTTP, FTP, SMTP). For data traffic, hybrid mobile stations can allocate downlink resources both on the DVB-T and the UMTS system.

For computational efficiency, the size of the scenario has to be restricted to seven UMTS cells in a hexagonal grid (1 km radius), and one DVB-T cell (20 km radius). Only the central UMTS cell is evaluated, the outer ring serves as a source of intra-system interference and to realistically model handover. The UMTS cluster and an underlying road map can be positioned at different locations relative to the DVB-T transmitter, in order to capture the various interference situations from co-sited UMTS/DVB-T transmitters to border situation with handover between two DVB-T cells.

Under the assumption of a downlink capacity shortage due to asymmetric traffic, we have focused on interference between a UMTS downlink and a neighboring DVB-T downlink. Both systems are assumed to have omni-directional antennae. For the UMTS system, power control is C/I-based, with a CIR target for the 12.2kbit/s speech service of –17.75dB for both up- and downlink, and an abrupt RLF limit of –21dB.

We assume hard handover with a handover margin of 3dB. Since a roadmap is necessary for mobility in our simulation framework, and since the choice of a roadmap is completely arbitrary, we chose a rectangular grid with turn probabilities according to the Manhattan grid described in [4]. The map covers the whole UMTS cell cluster, with a terminal velocity of 100km/h. A user is deemed to be satisfied if his call completes successfully.

II. WORST CASE RESULTS

Since no previous experience with the coexistence of UMTS and DVB-T was available, the DRiVE coexistence studies necessarily started with a worst case scenario. In our simulation model, the interference is governed by transmitter spectral masks and receiver filters, propagation losses and transmission power levels. While transmission masks are defined in the relevant standards [1][2][3], receiver filter characteristics are implementation dependent and not standardized. For our simulations, we assume perfect receivers, with all imperfections assumed to be included in the transmission mask (see. Section III). Power levels in UMTS are determined by the choice of a power class (class 2, max Tx power 27dBm), according to [2] for the UE. BS power has been parameterized with a per-link maximum power of 33dBm for the worst case simulations. For the results presented in section V, a refined model with a per-BS power budget of 43dBm has been used. DVB transmission power for a cell radius of 20km has been estimated at 80dBm on the basis of a Hata-Okumura path loss model for the small town suburban case [8], a required C/I of 11dB for the 16-QAM modulation scheme, an assumed shadowing variance of 10dB and an additional safety margin. For the simulations in section V, this power has been lowered to 74dBm, since the measurements described in section III showed a high resistance of the COFDM transmission scheme against adjacent channel interference, and thus a lower required minimum C/I at the DVB cell border.

Figure 2 shows the results in terms of the percentage of satisfied users (USC) for the UMTS downlink adjacent to the interfering DVB link, and for a location at the center and the border of the interfering DVB cell. While at the border of the DVB cell, the interference power has decreased sufficiently to not degrade UMTS operation, in the center of the DVB cell provision of a guard band is not suitable to ensure satisfactory operation. Instead, strategies for increasing the average wanted signal level at the cell border (e.g. shrinking the cell around the DVB interferer) promise better success without excessive guard bands. The impact of modifying the size of the center UMTS cell will need to be examined in a separate series of simulations.

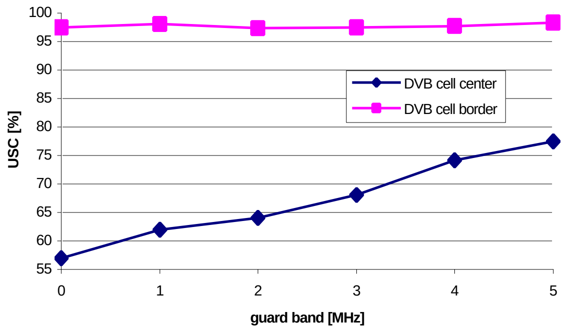

Figure 2: Worst case user satisfaction over GB

III. MEASUREMENTS

So far, simulations have been based on worst case assumptions derived from the relevant standards: the DVB transmission mask was chosen to be the envelope of the masks given in [1], and DVB transmission power was chosen high to meet the high protection requirements assumed in that document.

In order to evaluate the potential for improving system performance by using state of the art DVB transmission equipment, laboratory measurement have been performed within DRiVE with market-available DVB transmitters and receivers. Based on these measurements, modified protection requirements have been obtained, leading both to modified masks and power levels for a second set of simulations.

Measurement results presented in [5] indicate that the worst case assumptions made in section II. are overly pessimistic with regard to both the required C/I for sufficient DVB performance and thus the required DVB transmission power, and also regarding the shape of the transmission mask.

The DVB transmitters used for the DRiVE measurements represent those available for operation of the BBC DVB-T network operational in the UK. Those transmitters do exceed the ‘Critical Cases’ mask from [1] in some places, but correspond reasonably well looking at integrated out of channel power, which is the only criterion relevant for the simulations. The ‘Critical Cases’ mask represents a considerable improvement over the worst case mask used for the first results. However, the measurements at the same time illustrated that receiver nonlinearity, which is not covered in the simulation model at all, also plays an important role in overall system performance, somewhat degrading the improvement gained from using the better masks. Therefore, in [5] a modified transmission mask has been deduced, designed to include the nonlinear degradation caused by imperfect receivers into the transmitter signal. This was achieved by first identifying intermodulation products (IP) as the most important source of receiver degradation. Then, the overly optimistic ‘Critical Cases’ mask was deteriorated by adding intermodulation shoulders at a variable level. The IP level was now adjusted until the resulting theoretical protection ratio curves agreed with those obtained by laboratory measurements of available receivers[1]. Thus, a transmission mask was estimated that still allowed interference calculation by linear operations based on masks and filters, but included knowledge of the state of the art transmitter masks and the degrading non-linear effects in the receivers.

Figure 3 shows the worst case, best case and the modified DVB masks. From these masks, the Adjacent Channel Leakage (ACL) for a UMTS channel next to the DVB channel can be calculated as a function of the guard band between the two channels. The results of this calculation is presented in Figure 4, indicating a significant improvement over the worst case of the adjacent channel suppression even with the degraded DVB mask.

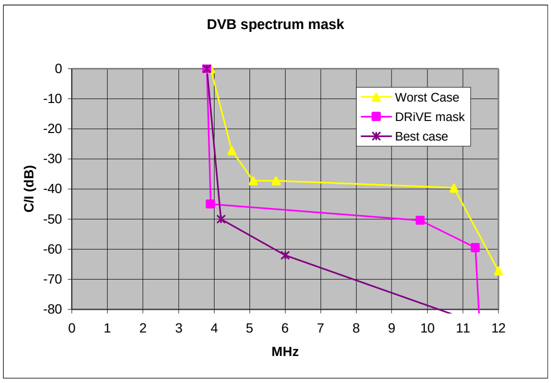

Figure 3: DVB spectrum masks

[1] It should be noted that within DRiVE, no UMTS receivers were available for measurements during the project duration. Therefore, receiver generated degradation was measured for DVB receivers, and the assumption was made that UMTS receivers will exhibit similar behaviour.

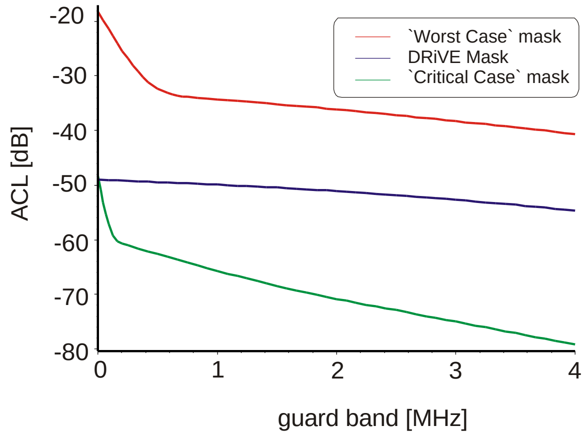

Figure 4: ACL over GB for DVB masks

IV. RESULTS OF REFINED SIMULATION MODELS

Based on the DRiVE measurement activities, two changes were made: in a first step, the robustness of the COFDM modulation scheme has been taken into account to reduce the required DVB transmission power from 80dBm to 74dBm. Additionally, the high shadowing variance assumed in the worst case scenario was reduced from 10dB to 7dB, which seems more appropriate for the suburban DRiVE scenario. Results from this simulation series are presented in section IV.A. In a next step, additionally the modified DVB transmission masks were used, thus further reducing the DVB interference due to the better ACL as seen in Figure 4. The corresponding results are presented in section IV.B.

A. Reduced DVB transmission power

Figure 5 shows the improved system performance for the changed parameters. Outside a region of about one UMTS cell size, acceptable performance is attainable with a guard band of 1MHz width. The loss in spectral efficiency caused by e.g. blocking the complete adjacent channel in one UMTS cell per DVB cell is far smaller than the loss incurred by providing a wide guard band over the whole area of the DVB cell.

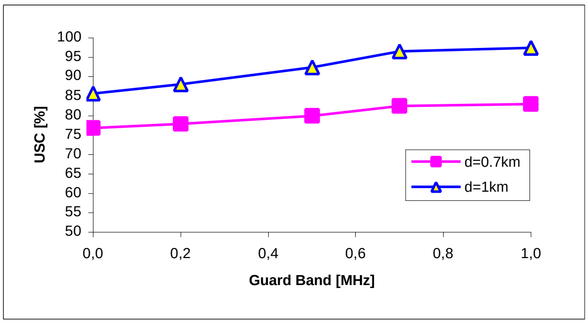

Figure 5: Improved performance

So far, we have looked at the performance of the UMTS system, which can readily be evaluated looking at the USC. For the DVB downlink, such a criterion is less

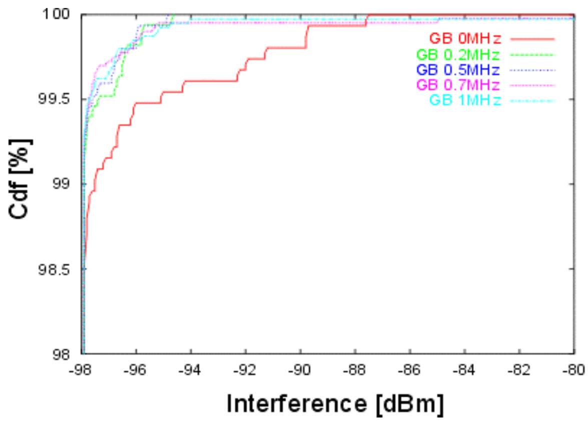

Figure 6:UMTS interference into DVB, border

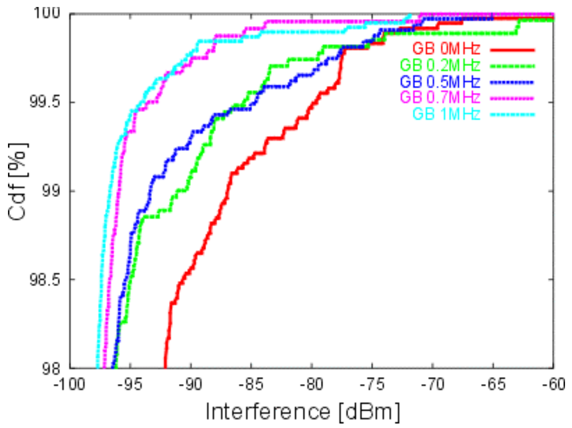

Figure 7: UMTS interference into DVB, center

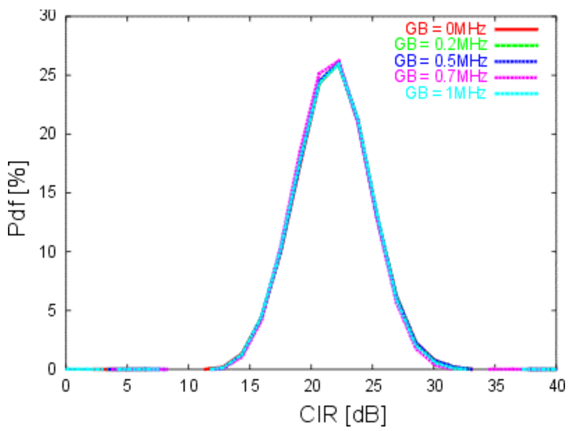

Figure 8: DVB CIR, border

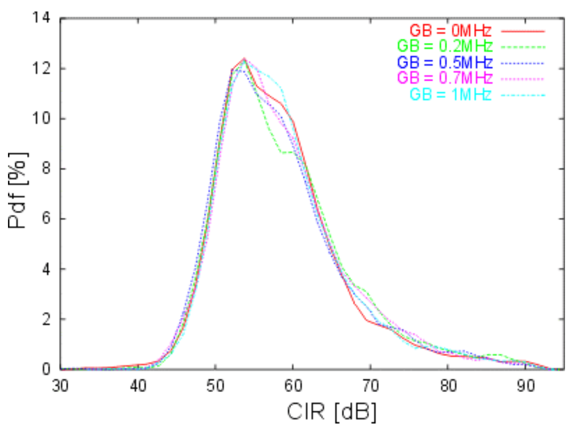

Figure 9: DVB CIR, center

easy to obtain. While [4] defines a USC for packet based links, it is based on packet throughput, which is largely dependent on higher layer protocols, and thus difficult to model in a link level simulator. However, looking at Figure 6 to Figure 9, it becomes clear that no performance problems need to be expected on the DVB side: interference is close to background noise at the border, where DVB signal levels are low and therefore UMTS power control limits the BS transmission power. In the center of the DVB cell, where due to high DVB interference UMTS power control reaches the BS power limit, the extremely high DVB wanted signal level guarantees favorable C/I conditions for DVB, while UMTS performance is the system bottleneck.
It therefore appears that even without abandoning the worst case DVB transmission mask, a DRiVE system can be operated, provided that in addition to a guard band, the channel adjacent to the DVB spectral region is blocked for the UMTS cell containing the DVB transmitter.

B. Additionally modified DVB mask

Figure 10 shows a further improvement of the UMTS performance, caused by using the modified DVB transmission masks according to Figure 3. According to these results, the region where noticeable degradation of UMTS GoS is to be expected is slightly smaller than one UMTS cell. Since the modified mask falls very steeply outside the channel passband, and is then almost constant in the adjacent channel region, it leads to an adjacent channel leakage which varies little with the width of the guard band (see Figure 4). Consequently, guard band width has little effect on the USC, and can be reduced to almost zero, if the UMTS cell containing the DVB BS is considered blocked for the channel adjacent to the active DVB channel.

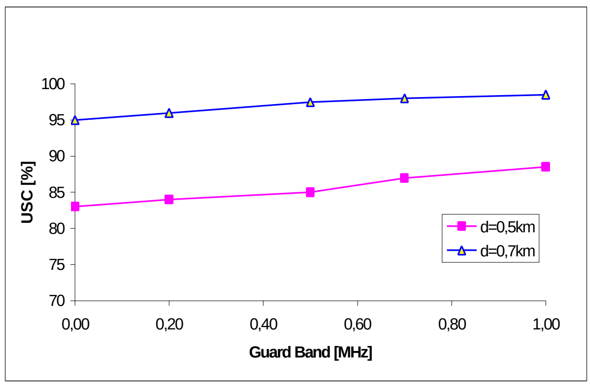

Figure 10: Performance with modified DVB mask

V. CONCLUSIONS AND FUTURE WORK

The studies performed in DRiVE have shown that coexistence of DVB-T and UMTS in a DRiVE hybrid network is possible. While the high power of the DVB transmitter creates considerable adjacent channel interference in a neighbouring UMTS channel, with a combination of guard band and minimum spatial separation of the DVB transmitter and victim UMTS cells occupying the adjacent channel a satisfactory grade of service can be obtained.

In a series of simulations, estimates of minimum required guard bands have been determined, in order to reach satisfactory GoS in the UMTS system. The results of these simulations were shown to be especially sensitive to the shape of the DVB transmission mask. Assuming a worst case transmission mask as permitted by the relevant DVB standard, the simulations predict a severe capacity loss in the UMTS system, even with an extremely wide guard band.

However, the results of the DRiVE laboratory measurements indicate that state of the art DVB transmitters perform much better than required by the standard – they almost reach the performance of the demanding 'Critical Cases' mask also defined in the DVB standard.

Given such rather clean transmitters, the measurements also indicate that neglecting the influence of receiver imperfections is no longer possible. Therefore, a modified, degraded transmission mask for the DVB system has been chosen, which tries to account for receiver imperfections by artificially degrading the transmitter performance.

Using this modified mask, simulations results predict that satisfactory performance of the critical UMTS system can be attained at a guard band of approximately 500kHz over almost the whole DVB cell area. Only an area of approximately one UMTS cell around the DVB interferer will experience severe capacity loss, and therefore has only restricted access to the frequency channel adjacent to the DVB transmitter. However, since this degraded area is small compared to the total area of the DVB cell, the loss of spectral efficiency caused by DVB interference is very small.

While the impact of DVB interference on UMTS can be significant, simulation results indicate that UMTS adjacent channel interference will have a negligible effect on DVB. Mainly due to the availability of power control in the UMTS system and the high robustness of DVB against ACI on the one hand side, and the high power of the DVB transmitters on the other side, interference into DVB is not the limiting factor for overall system performance in a DRiVE hybrid radio system.

Results from the DRiVE coexistence studies have identified several fields for further research, in order to obtain more detailed and accurate predictions of spectral efficiency of the DRiVE system. First, since no UMTS receivers were available for measurement, receiver imperfections found in the DVB receivers have been assumed to be similarly present in the UMTS receivers. Once UMTS receivers are available, additional laboratory measurements covering DVB interference into UMTS would be beneficial to confirm this assumption.

Secondly, cell sizes have so far been assumed to be fixed. However, shrinking of the UMTS cell containing the DVB interferer will provide increased average wanted signal for UMTS, and thus improve transmission conditions at the expense of additional infrastructure, but without the loss of spectrum for guard bands or blocked frequency channels.

Also, the measurement results have shown that the commonly used description of interference by linear integration of one system's adjacent channel leakage into the other system's passband is not accurate, since non-linear effects in the receivers can dominate the performance in the case of relatively clean transmitters. Therefore, the mask and filter-based approach of modelling adjacent channel interference, though commonly used in system evaluation, needs further refinement.

VI. ACKKNOWLEDGEMENTS

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