Spectral Coexistence of DVB-T and UMTS in a Hybrid Radio System

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Abstract: *The scarcity of available radio spectrum presently limits the extension of the modern, multi media enhanced internet into the mobile domain. One approach to alleviate this limitation is the development of flexible, optimized mobile radio networks, which will be able to adapt to the spatial and temporal variation in capacity demand, in order to increase the overall spectral efficiency of the joined set of radio networks. However, this flexibility creates new challenges on several system levels. One of them is the dynamic changing of spectral neighborhood relations, and thus of interference between systems. While in a static scenario the frequency planning is predetermined and fixed, a dynamic, adaptive allocation of spectrum requires flexible prediction of expected interference between different radio systems. Required guard bands decrease the overall spectral efficiency of the system, and therefore need to be minimized, or taken into account as a constraint when making optimizations. A simulation-based approach for assessment of the coexistence of DVB-T and UMTS in a hybrid radio system with flexible, dynamic spectrum sharing is presented. A simplified simulation scenario has been developed in order to cope with the computationally expensive modeling of a multi-cellular, mobile communication system. First results are presented for the interference and degradation of UMTS operation in the presence of a neighboring DVB-T system. In an outlook, possibilities for future improvements to the simulation results are shown.*

I Introduction

Currently, the available radio spectrum is divided into fixed and non-overlapping blocks assigned to different services and standards. Guard bands are introduced between frequency bands allocated to systems that would otherwise interfere each other due to out-of-band emissions. This static paradigm of spectrum usage ensures predictable and negligible interference between different Radio Access Networks (*RAN*s). At the same time the number of combinations of two RANs operating in adjacent spectrum and thus necessitating investigations into co-existence is kept small.

However, this static and spatially uniform allocation of spectrum seems to be sub-optimal with respect to spectral efficiency in the future multi-radio environment, comprising UMTS, GPRS, DVB-T and DAB, because the individual systems' loads are expected to be spatially and temporally variable. Additionally, it is obvious that contemporary multimedia data traffic consists of different categories with widely diverging traffic properties (asymmetry of up- and downlink, Quality of Service (*QoS*) requirements, required data rate, delay constraints, etc.). Each of the available radio systems is developed and optimized for a different type of traffic, opening up a great potential for optimization and cooperation when assigning different types of traffic to the different radio systems.

Given the constraints of high cost and limited availability of radio spectrum, efficient spectrum usage is key to the economic success of third generation cellular systems. One novel concept to use available resources more efficiently is the combination of existing radio systems into a coordinated, hybrid system, in order to combine the strengths and capabilities of the individual systems. Additionally, while ideally transparent to the user, the combination of systems adds a degree of freedom in the sense that at any time, the most spectrally efficient transport system can be chosen, depending for example on QoS requirements and traffic characteristics. If additionally the allocation of spectral resources to the individual systems were flexible, currently unused spectrum could be reallocated to another, presently overloaded system, thus again increasing overall spectral efficiency.

II DRiVE System Concept

The European research project DRiVE (Dynamic Radio for IP Services in Vehicular Environments) aims at enabling spectrum-efficient high-quality wireless IP in a heterogeneous multi-radio environment to deliver in-vehicle multimedia services. DRiVE addresses this objective on three system levels: The project investigates methods for the coexistence of different radio systems in a common frequency range with dynamic spectrum allocation. DRiVE develops an IPv6-based mobile infrastructure that ensures the optimized inter-working of different radio systems (GSM, GPRS, UMTS, DAB, DVB-T) utilizing new dynamic spectrum allocation schemes and new traffic control mechanisms. Furthermore the project designs location dependent services that adapt to the varying conditions of the underlying multi-radio environment.

This paper focuses on the aspect of coexistence of different radio systems in neighboring frequency bands, with the simplifying assumption of a multi-radio environment consisting of DVB-T and UMTS. It assumes as an example a dynamic sharing of the frequency band presently allocated in Europe to TV broadcasting (470-806/862 MHz). In this frequency range, a hybrid radio system is assumed to operate cooperatively, with individual radio bearer systems being coordinated and integrated by a DRiVE backbone and higher level optimization and routing functionality.

The spectrum allocation to the participating individual systems is assumed to be flexible, in order to accommodate spatial and temporal variation in the bandwidth requirements of the individual systems. For the purpose of this paper, we assume the presence of a network entity that performs fair spectrum allocation, as well as another entity responsible for routing traffic to individual radio bearer systems. The routing can be based on the QoS requirements of the traffic and on the available capacity in the systems.

III Spectral Coexistence

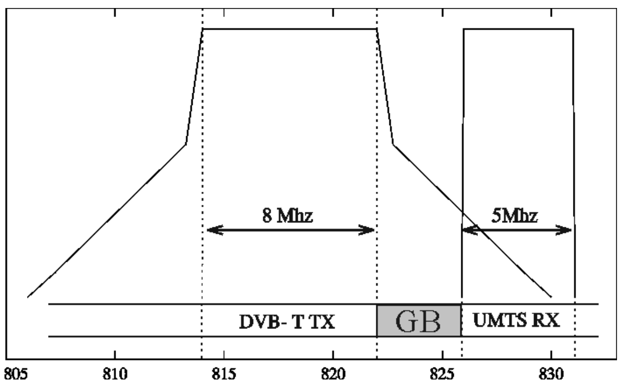

Figure 1: Mask and filter in an ACI scenario

In the hybrid system outlined above, DVB-T and UMTS are spectral neighbors, and therefore any out-of-band energy emitted by one system due to transmitter imperfections will interfere with the adjacent system. Figure 1 shows such and 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.

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.

Generally, the level of ACI is a time varying stochastic process due to station mobility, power control and handover. In practice, ACI is only one of several mechanisms that create interference between radio systems. Additional effects[1] may even dominate, but are difficult and computationally expensive to model in a multi-cellular environment with many simultaneous victims and interferers. Therefore, apart from thermal noise, we consider system interference as the sum of only the intra-cell interference due to imperfect orthogonality of CDMA codes, intra-system interference from neighboring cells of the same radio system, and ACI from the second radio system.

[1] e.g. inter-modulation, quantization effects in the receiver, etc.

In order to asses the impact of those neglected effects, protection ratio measurements are performed in DRiVE. Based on results from these measurements, it will later be possible to derive modified transmitter and receiver masks, which can serve as an abstraction for previously neglected receiver properties, and therefore improve simulation results.

IV Radio Network Simulation

While analytic worst case calculations can provide an upper boundary for the required guard bands, considerable gains can be obtained from statistical analysis of the interference situation by simulation. Since the session arrival process, user mobility and channel properties are statistical processes, and the common service quality criteria are themselves based on user satisfaction statistics, stochastic simulation is a suitable method to optimize the tradeoff between system protection and spectral efficiency [4].

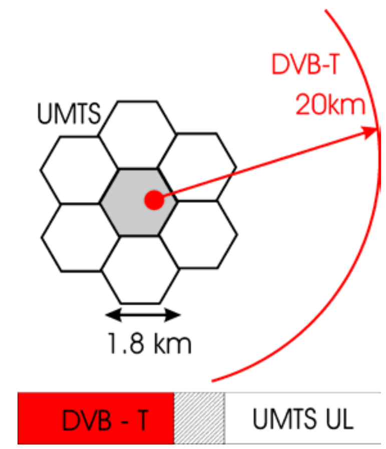

Figure 2: Simulation scenario

For the purpose of the studies undertaken for this paper, a simulation platform developed at the Chair for Communication Networks has been extended to support hybrid operation of the systems, where up- and downlink of one communication session are provided by different radio systems. 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.

IV.I Modeling

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

The simulation tool supports UMTS hard handover and both level-based and C/I-based power control.

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.

IV.II Simulation scenario

Due to the frequent, computationally intensive interference calculations, the size of the scenario has to be restricted to seven UMTS cells in a hexagonal grid (900 m radius), and one or two DVB-T cells (20 km radius, see Figure 2). 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.

For first results, we have focused on interference between a UMTS uplink as a victim, and a neighboring DVB-T downlink as the interferer with a constant power of 80dBm. 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 [5]. The map covers the whole UMTS cell cluster according to Figure 2, with a terminal velocity of 100km/h.

User satisfaction is determined according to [5] criteria.

V Results

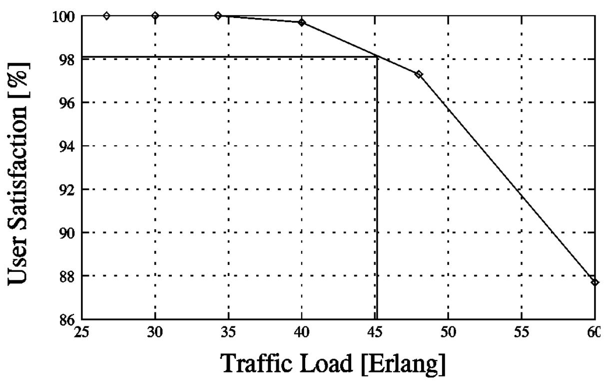

Figure 3: UMTS base load at 2% drop rate

As a first step, a baseline for comparison has been established by simulating a UMTS system without additional interference from DVB. The UMTS system carries a load of approx. 45 Erlang of circuit-switched voice calls, which has been determined to cause a total call drop rate (UL and DL) of 2%, according to a simulation series shown in Figure 3.

In the following simulations, a DVB-T transmitter has been simulated co-sited to the base station of the central UMTS cell, with increasing guard band between the two systems. Figure 4 shows the degradation in user satisfaction which is caused by the additional interference from the DVB-T transmitter. Under our given assumptions, a fairly large guard band of 4MHz is required, in order to bring call drop rates down to 5%.

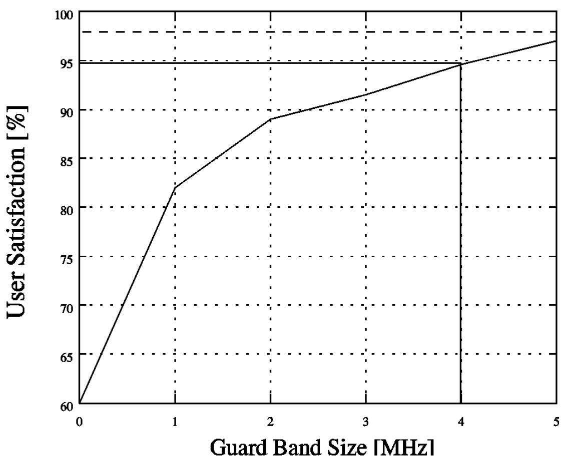

Figure 4: Required guard band size

However, it should be noted that this scenario is interesting mainly as a proof on concept, and for validating the simulator implementation. It has been chosen as a test case, since it provides BS to BS interference, which is easier to validate since the BS have a fixed position with respect to the interferer, and therefore, in the absence of fading from moving objects, experience a constant additional interference from the DVB BS. In addition, the co-siting leads to a worst case interference in our simulation framework, since it leads to the lowest coupling loss between the dominant interferer and the victim BS.

Nevertheless, in practical implementations, this scenario is not feasible and desirable for two main reasons:

- First, due to the extremely low coupling loss from the co-siting, the above-mentioned non-linear effects in the receiver would lead to excessively bad performance in a real life system.
- And second, from a commercial point of view, a scenario with additional DL capacity in the ‘DRiVE band’ is more likely to be implemented, since the asymmetric nature of the internet traffic assumed for DRiVE requires additional DL resources.

Two additional shortcomings of the present state of the simulation environment are highlighted by this validation scenario:

- in the given interference scenario, BS to BS interference is observed, with a very high-powered transmitter as interferer. Both antennae are omni-directional, and very close to each other. On the one hand side, this leads to the above-mentioned low coupling loss with the corresponding non-linearity problems. Additionally, path loss in this case should be modeled as line-of-sight (*LOS*) instead of Hata.. Due to the large antennae commonly used in DVB-T, this LOS or quasi-LOS case can be expected to appear frequently. Therefore, additional thoughts on the path loss modeling are necessary.

- first results from the DRiVE measurements show that the spectrum masks given in the DVB-T standard are pessimistic. Some results even indicate that the main source of interference lies in the receiver, instead of the ACI from the neighboring transmitter.

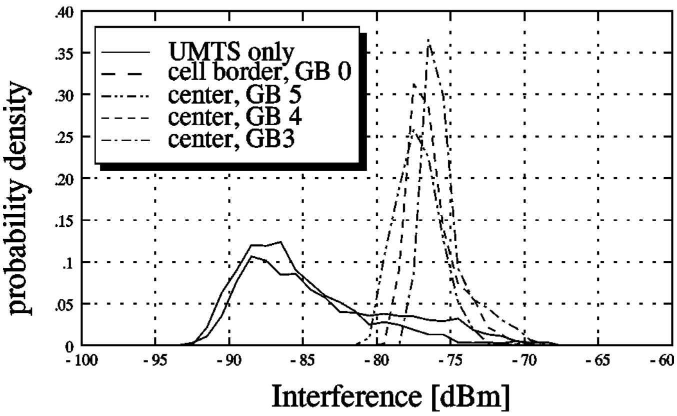

Figure 5: Probability density distribution of interference

In order to visualize the influence of the DVB-T interference in comparison to the UMTS intra-system interference, Figure 5 gives the probability density distribution of the interference experienced by the victim UMTS system, compared to single system operation, and to operation at the border of the 20km DVB-T cell, where the interference level is obviously lower due to the higher coupling loss at large distances. Also, Figure 5 shows that at the border of the DVB-T cells, undisturbed system operation would be possible even without a guard band.

Finally, Figure 6 gives the probability distribution of the transmit power of the mobile terminals. The higher levels of interference in the three curves from the interfered central scenario are a result of C/I-based power control, which tries to maintain the target C/I by pushing a large share of the mobile terminals closer to their power limit of 24dBm.

VI Conclusions and Future Work

In this paper, we have presented first results from the coexistence studies in DRiVE. From within the set of assumptions made in the modeling, the results represent a worst case scenario, requiring a rather large guard band. However, because of the reasons described in section V, the scenario is not feasible in practice, and should therefore regarded as proof of concept and validation of the implementation.

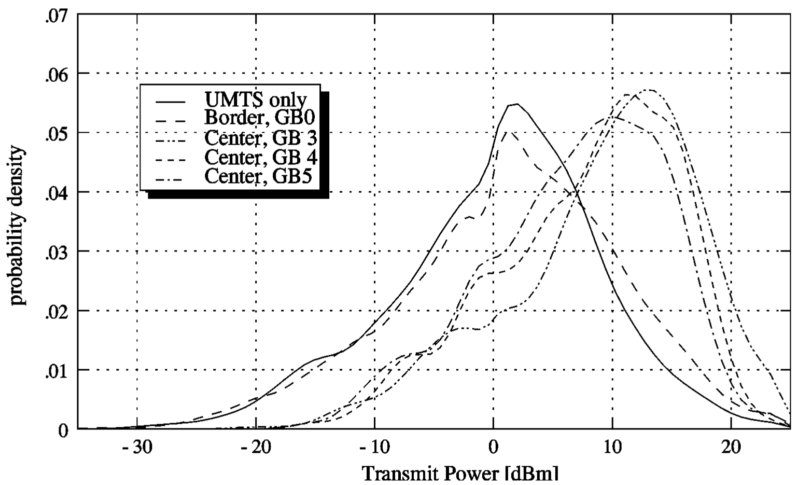

Figure 6: Uplink transmit power of the mobile stations

Future work will focus on refining the interference modeling. Based on results from the DRiVE measurements, knowledge of real system performance beyond the standardized spectrum masks can be included. Together with such knowledge about the ACI performance of DVB-T receivers, a user satisfaction criterion according to [5] will be included in the DVB part of the simulator, comparable studies for DVB as a victim system will be performed. The focus will be on DVB-T interference into the UTRAN DL and vice versa, since at the core of DRiVE is the need for additional DL capacity.

From the present and future results, additional simulations with lower system load in the UMTS system can derive the capacity loss in UMTS incurred through the additional interference, given a fixed user satisfaction requirement. Together with the loss through the guard band, this gives the total loss of spectrum efficiency due to the interference at the spectral border between the two radio systems. This result will serve as input to the DRiVE dynamic spectrum allocation (*DSA*) activity, as it constitutes a constraint in the optimization function for DSA.

VII Acknowledgements and References

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