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Spectral Coexistence Of Narrowband And Wideband IMT-2000 TD-CDMA Systems

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Abstract

In this paper the mutual interference between two 3G TDD systems operating in adjacent frequency bands is evaluated. The capacity loss due to spectral coexistence is evaluated for the UTRA-TDD system and its low-chiprate option. It can be observed that with the current specification of allowed sideband emissions and required filter characteristics both systems, narrowband and wideband TDD, can coexist without essential mutual impact on capacity.

1 Introduction

The main objective of this paper is the analysis of the coexistence of time division duplex 3G systems, namely the UMTS TDD and the Chinese TD-SCDMA system which has been integrated into the 3GPP UMTS standard as the so-called low-chiprate or narrowband option. Some licenses that have already been assigned do not claim a certain 3G system but allow any member of the IMT-2000 family to be operated in the licensed frequency band. Therefore two different TDD systems can operate in adjacent frequency bands. Since in general those systems are not synchronized with each other, a number of interference situations arise, especially mobile-to-mobile and base-to-base interferences are typical constellations in TDD systems.

In [1] a method for the simulative evaluation of adjacent channel interference in CDMA-systems has been introduced that is based on the method proposed in [2]. The spectral compatibility of UTRA Systems with hexagonal cell-shape is also investigated in [3, 4] while [5] deals with the adjacent channel interference in a single-operator hierarchically structured network.

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The following sections explain the adjacent channel interference and the capacity evaluation in the single-operator and in the multi-operator case, i.e. without and with adjacent channel interference for different scenarios.

2 Narrowband and Wideband IMT-2000 TDD CDMA Systems

3GPP considers two options for a time division duplex (TDD) CDMA system: 3.84Mcps TDD (wideband TDD, based on the European TD-CDMA proposal for the IMT-2000 radio transmission technology) and 1.28Mcps TDD (narrowband TDD, based on the Chinese TD-SCDMA proposal for the IMT-2000 radio transmission technology). 3.84 Mcps TDD has a channel spacing of 5MHz and 1.28 Mcps TDD has a channel spacing of 1.6 MHz.

Both options have a 10ms frame structure in the time domain, but a different number of time slots per frame: 3.84 Mcps TDD has 15 slots of equal length which may be used for UL (uplink, i.e. MS to BS) or DL (downlink, i.e. BS to MS) communication, 1.28 Mcps TDD has two 5 ms subframes. Each subframe has a DL timeslot, a 352 chip period (consisting of a DL pilot, a guard period and an UL pilot) and 6 further timeslots where at least the first one is an UL timeslot. Furthermore, both options have different transmitter and receiver characteristics (see section 3).

The objective of this paper is a coexistence investigation of two uncoordinated operators A and B operating TDD CDMA systems in adjacent frequency bands. Each system consists of roaming mobile stations (MS) with speech services under vehicular propagation conditions and macro cells (radius: 500m) with fixed base station (BS) positions. A random shift is used for the distance between the hexagonal cell grids of system A and B.

Assuming one station of system A (MS or BS) is receiving (called the victim station) then it may suffer from different kinds of interference:

- intra-cell interference from system A ,
- inter-cell interference from neighbour cells of the same system,
- interference from MS or BS of system B. Because of non-ideal rise of transmit and receiver filter flanks a leakage of transmit power in adjacent bands and also a reception from adjacent bands can not entirely be prevented.

The first two parts are called co-channel interference and the last part is called adjacent channel interference.

3 Adjacent Channel Interference

In the sense of our investigations, one system can interfere with the other if the power density spectrum of the transmitted signal is not limited to the nominal carrier bandwidth, which is the normal case for digital communication systems. The Adjacent Channel Interference Power I_{adj} is defined as

$$I_{\text{adj}} = \frac{P_{\text{TX}}}{L_{\text{CL}}} \int_{-\infty}^{+\infty} \Phi(f - \Delta f)|H(f)|^2 df, \qquad (1)$$

where $\Phi(f)$ is the power density spectrum of the transmitted signal of one interfering station of the interfering system. $H(f)$ denotes the receiver filter's transfer function, Δf is the channel spacing between the carrier frequency of the interfering and the perturbed station. The pathloss between an interfering and the perturbed station is called the coupling loss, denoted as L_{CL}.

To limit the interaction between systems in adjacent frequency bands, the standards specification define the maximum allowed transmitted power density as well as requirements on the receiver filters.

In the receiver, a non-ideal root raised cosine filter is taken into account. The transfer function of this filter, similar to the ideal root raised cosine, is shown in equation 2.

$$H(f) = \begin{cases} 1 & |f| < (1-r)w \\ \cos\left(\frac{\pi}{4r}\left(\frac{|f|}{w} - 1 + r\right)\right) & w(1-r) < |f| \\ & |f| < (1+r)w \\ \text{ACS} & \text{else} \end{cases}, \qquad (2)$$

where ACS is the Adjacent Channel Selectivity, i.e. the wideband attenuation of the filter.

The Adjacent Channel Interference Ratio (ACIR) ρ quantifies the portion of transmitted power that takes effect as adjacent channel interference. It is defined as follows:

$$\text{ACIR} = \rho = \int_{-\infty}^{+\infty} \Phi(f - \Delta f)|H(f)|^2 df \qquad (3)$$

and specifies the crosstalk between the adjacent channels of the interfering and the perturbed system. Table 1 summarizes the Adjacent Channel Interference Ratios for the coexistence scenarios investigated in this paper.

Table 1: Adjacent Channel Interference Ratios for different scenarios

interfering	perturbed	Δf	ACIR
1.28 Mcps MS	1.28 Mcps MS	1.6 MHz	29.6 dB
1.28 Mcps MS	1.28 Mcps BS	1.6 MHz	31.6 dB
1.28 Mcps BS	1.28 Mcps MS	1.6 MHz	31.6 dB
3.84 Mcps MS	3.84 Mcps MS	5 MHz	29.6 dB
3.84 Mcps MS	3.84 Mcps BS	5 MHz	32.7 dB
3.84 Mcps BS	3.84 Mcps MS	5 MHz	32.7 dB
1.28 Mcps MS	3.84 Mcps BS	3.3 MHz	34.4 dB
1.28 Mcps MS	3.84 Mcps MS	3.3 MHz	30.4 dB
1.28 Mcps BS	3.84 Mcps MS	3.3 MHz	31.8 dB
3.84 Mcps MS	1.28 Mcps BS	3.3 MHz	29.9 dB
3.84 Mcps MS	1.28 Mcps MS	3.3 MHz	28.2 dB
3.84 Mcps BS	1.28 Mcps MS	3.3 MHz	32.0 dB

The lowest ACIR can be found for the wideband TDD mobile perturbing a narrowband TDD station. It can be expected that this will lead to a significant interference power in the perturbed system.

4 Determination of Capacity

The capacity is expressed as the maximum number of users per cell that can be carried with a given quality of service requirement. In our investigation, all users use the same service.

The maximum number of users N that can be carried for a given quality of service requirement is determined with a snapshot simulation technique. Herein, the mobiles are placed at random locations within a grid of hexagonal omni-directional cells and assigned to the best-serving base-station. Then power control is performed until a stable status is reached. After that the link quality is evaluated and taken as a criterion to judge if the quality of service requirement is met. The percentage of links suffering from bad quality in terms of carrier-to-interference ratio (CIR) is called outage probability. In our investigation the maximum capacity is reached if the number of users per cell corresponds to an outage probability of 5% which implies a coverage probability of 95%. Since CDMA-systems are interference limited, the outage probability is a suitable criterion as long as the cell size is fixed and the link budget for uplink and downlink is balanced.

The outage criterion is used to determine the single-operator network capacity, i.e. the network capacity without adjacent channel interference. From the simulations we know the mean interference power at the victim receiver, called reference interference power. The capacity for the multi-operator case is therefore evaluated by reducing the load in the victim system as long as the total interference, i.e. co-channel and adjacent-channel interference, exceeds the reference interference level. This method is valid since the interference power directly affects the link budget and therefore the cell radius that can be reached with a given coverage probability.

Due to the snapshot character of the used simulation method the coexistence of the two TDD systems is considered for time instants only. In the simulation, there is no time alignment between the frame structure of the victim system and the frame structure of the interferer system, i.e. for a given victim station the simulator assumes that all the interferer stations are transmitting at the observed time instance. The evaluation is done on a burst basis, i.e. the interference calculated for a time instance is assumed to be present for the whole duration of the victim links burst. This assumption leads to a maximum interference energy observed within one slot.

5 Simulation Parameters

The pathloss models and the simulation scenario are those described in [6] for the vehicular test environment with omni-directional macro cells of 500m radius. Shadowing values are auto- and cross-correlated depending on the distance and on the angle of arrival. Tabular 2 summarizes the main simulation parameters. The values are taken from [7, 8, 9] or determined by own simulations. For both systems we assume joint detection receivers. The C/I requirements have been determined by link-level simulations for the vehicular a environment [6] and with the presumption of ideal receivers.

Table 2: Simulation Parameters

	UTRA TDD	TD-SCDMA
max Tx Pow UL [dBm]	30	24
max TX Pow DL [dBm]	43	43
noise power UL [dB]	-103	-106
noise power DL [dB]	-99	-104
service	speech	speech
net rate [kbps]	8	8
req. C/I UL [dB]	-8.1	-6.0
req. C/I DL [dB]	-5.6	-4.6
cell radius [m]	500	500

6 Single-Operator Capacity

The single operator capacity is determined as described in section 4.

6.1 Wideband TDD

Figure 1 shows the simulated outage probability depending on the number of active users per cell for the uplink and the downlink. For the reference outage probability of 5% the UTRA TDD system is able to carry a traffic of about 7.5 users per slot in the downlink and 14.5 users per slot in the uplink. The capacity for the downlink is significantly lower. This is on one hand caused by the higher required C/I at the mobile station and on the other hand by the different power control requirements for up- and downlink. While in the uplink each link is controlled to meet exactly a given receive power or the given C/I requirement, respectively, the downlink power control has to ensure that within one timeslot the powers of all active codes may be balanced to within a range of 20dB [7].

6.2 Narrowband TDD

The single-operator simulation results for the narrowband TDD system are shown in Figure 2. Please note that no smart antennas have been taken into account. For the reference outage probability of 5% the narrowband TDD system is able to carry a traffic of about 6 users per slot in the downlink and 8.6 users per slot in the uplink.

7 Multi-Operator Capacity

Since adjacent channel interference can cause a degradation of service quality, the additional interference

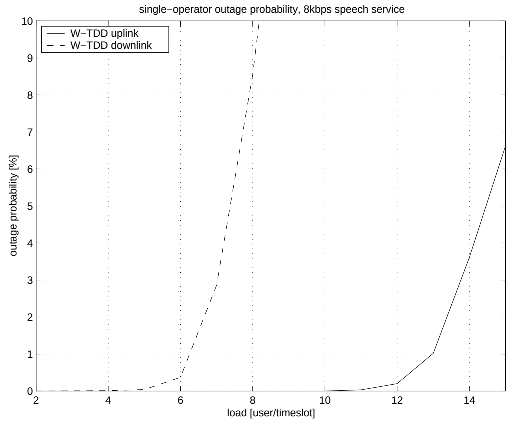

Figure 1: Single-operator outage probability for wideband TDD

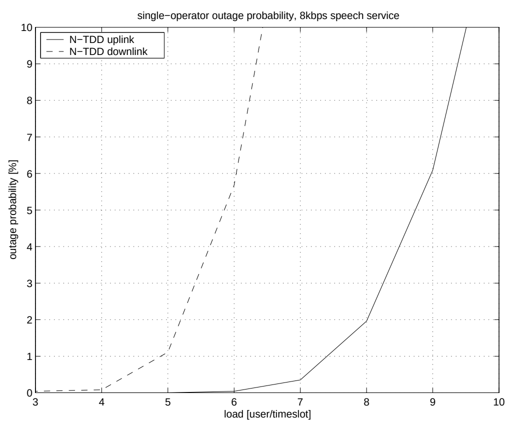

Figure 2: Single-operator outage probability for narrowband TDD

has to be compensated by reducing the load in the perturbed system. Let N be the maximum number of users that can be active at a time having a required service quality. Then, the relative capacity loss due to adjacent channel interference is

$$\xi = \frac{N(I_{\text{adj}} = 0) - N(I_{\text{adj}})}{N(I_{\text{adj}} = 0)}. \tag{4}$$

According to equation 4 the multi-operator capacity is defined as the network capacity in the presence of adjacent channel interference power originating from an other system in an adjacent frequency band. The Number $N(I_{\text{adj}} = 0)$ is known from the single-operator simulations while $N(I_{\text{adj}})$ has to be determined by a number of simulations. Thereby, the load in the interfering system is kept constant for all simulations while the number of users in the perturbed system is reduced for each simulation as long as the quality of service, i.e. the outage probability, equals the value measured in the single-operator simulations.

Figure 3 exemplarily shows the noise rise in the perturbed narrowband TDD system's downlink in the in the multi-operator case, i.e. with additional adjacent channel interference. The noise rise is defined as the relation between the total interference power and the thermal noise power.

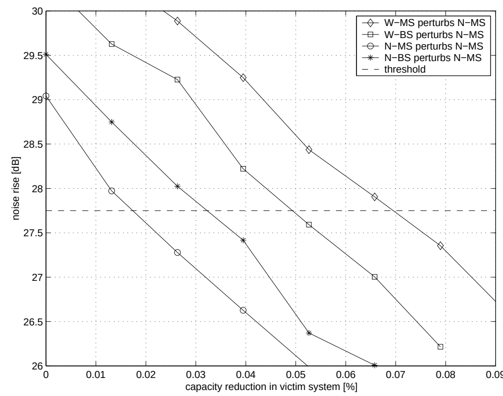

Figure 3: Multi-operator noise rise for a perturbed narrowband TDD mobile station

The dashed line figures out the single operator noise rise in the downlink. To determine the capacity loss, the load is normalized to the single operator reference value.

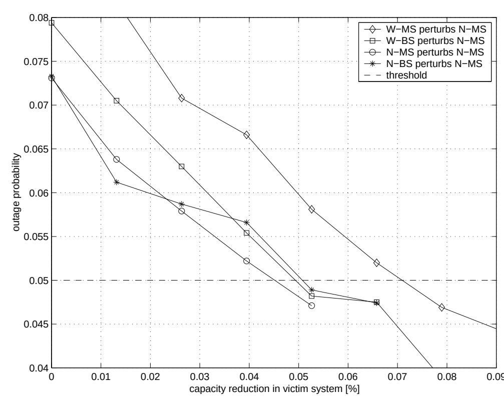

Figure 4: Multi-operator outage probability for a perturbed narrowband TDD mobile station

Figure 4 shows the outage probability in the perturbed TDD downlink as a function of the load reduction in the victim system. As one can observe, the resulting capacity losses (with respect to a reference outage probability of 5%) correspond to the results achieved using the interference criterion if the adjacent channel interference is relatively high. For the interfering narrowband system the calculated capacity losses based on the outage criterion are higher than those calculated using the noise rise criterion. This is on the one hand caused by the increased variance of the total interference power and on the other hand on statistical inaccuracies within the simulation.

Since the noise rise based results are statistically more confident, we show these results in the following although the outage criterion may cause slightly higher losses. Table 3 summarizes the results of all coexistence simulations.

Table 3: Simulated capacity losses in different coexistence scenarios

interfering station	perturbed station	loss [%]
1.28 Mcps MS	1.28 Mcps MS	1.9
1.28 Mcps MS	1.28 Mcps BS	3.2
1.28 Mcps BS	1.28 Mcps MS	3.1
3.84 Mcps MS	3.84 Mcps MS	5.8
3.84 Mcps MS	3.84 Mcps BS	5.1
3.84 Mcps BS	3.84 Mcps MS	5.4
1.28 Mcps MS	3.84 Mcps BS	1.5
1.28 Mcps MS	3.84 Mcps MS	2.0
1.28 Mcps BS	3.84 Mcps MS	3.1
3.84 Mcps MS	1.28 Mcps BS	7.6
3.84 Mcps MS	1.28 Mcps MS	7.0
3.84 Mcps BS	1.28 Mcps MS	4.9

One can observe that the interference originating in a wideband TDD system has the most distinctive effect. High user densities and wide power density spectra lead to a higher capacity loss than caused by an interfering narrowband TDD system. As already shown in Table 1, the ACIR of a wideband TDD mobile station perturbing a narrowband station is low. Therefore the highest capacity losses can be observed for this constellation.

8 Conclusions

In this paper, a method for estimating capacity losses due to spectral coexistence of UTRA TDD systems has been applied. To compensate the investigated additional adjacent channel interferences, a load reduction of at the most 7.6% can be necessary if the interfering system is fully loaded. One can observe that the interferences originating in an wideband TDD system have more influence of the perturbed system's capacity than the interferences from the narrowband system. This is mainly caused by the higher user density in the wideband system that leads to smaller coupling loss. Since we presented a worst case macrocellular scenario one can conclude that both systems, narrowband and wideband TDD, can coexist without essential mutual impact on capacity.

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