A Channel Filter With Variable Adjacent Channel Selectivity For UTRA-FDD/TDD

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Abstract **- A statistical analysis of ACS factors for an UTRA mobile terminal receiver is presented. A variable ACS channel filter is also described and analysed. UTRA-TDD has an average ACS of 19dB corresponding to an average filter length of 11 taps. It is 75 percent more efficient compared to the specification ACS of 33dB, which corresponds to a filter length of 41. UTRA-FDD has an average ACS of 16.26dB corresponding to an average filter length of 7 taps. This is a greater efficiency improvement of 82 percent compared to the specification. The analysis clearly demonstrates that a receiver channel filter with a variable ACS in the mobile terminal is highly efficient compared to a fixed ACS filter that meets the specifications.**

I. INTRODUCTION

This paper presents a statistical analysis of adjacent channel selectivity (ACS) factors for UMTS terrestrial radio access (UTRA) mobile receivers. A variable ACS channel filter is also described and analysed. The ACS factor determines the filter length for the channel filter in the receiver. The channel filter attenuates out-of-band signals, referred to as adjacent channel interference (ACI), and only allows in-band signals to pass. A statistical analysis is performed to demonstrate that such a filter is highly efficient compared to a fixed ACS channel filter. In terms of hardware implications, it is power efficient thus resulting in higher talk and standby times.

UTRA includes two duplex modes, frequency division duplex (FDD) and time division duplex (TDD). Figure 1 presents the two UTRA modes.

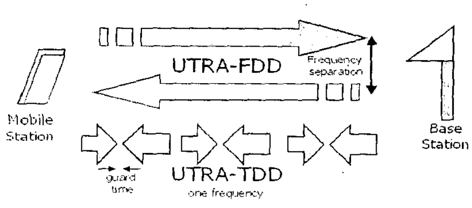

Figure 1. UTRA-TDD and UTRA-FDD modes

In UTRA-FDD, the uplink and downlink transmissions use two separated radio frequency bands. In UTRA-TDD, uplink and downlink transmissions are carried over same radio frequency by using synchronised time intervals. Time slots in the physical channel are divided into transmission and reception part. Information on uplink and downlink are transmitted reciprocally [1, 2]. This makes TDD mode susceptible to ACI as nearby mobile stations (MS) and base stations (BS) cause interference to each other depending on frame synchronisation and channel asymmetry. The UTRA-TDD operation has a near far problem of receiving out-of-band signal powers from both adjacent mobile and base stations. Figure 2 presents a multi-operator downlink ACI scenario in UTRA.

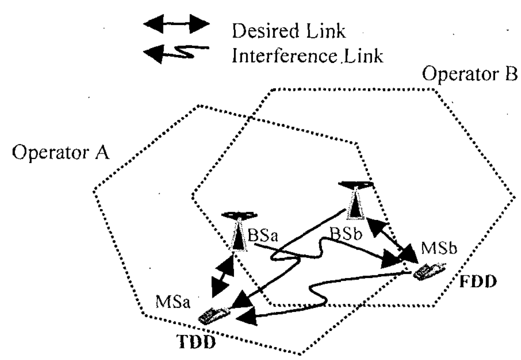

Figure 2. Downlink ACI scenario in UTRA

Two interference sources exist in the downlink for UTRA-TDD: adjacent MS and adjacent BS. The interference overlaps are BS→MS and MS→MS. If adjacent operators have synchronised frames and employ the same asymmetry, it would eliminate MS→MS interference. This cannot be assumed in practice and hence interference is experienced from both sources dependant on frame synchronisation and asymmetry. One interference source exists in the UTRA-FDD downlink: BS→MS.

II. ADJACENT CHANNEL SELECTIVITY

ACS is the stop-band dB level of the channel filter in the receiver at the +/-5MHz and +/-10MHz channel spacing in the adjacent channels. In this paper, the focus is on the +/-5MHz adjacent channel. Previous work in [3] explored variable ACS factors in UTRA-TDD. In this section, UTRA-

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FDD ACS factors will be analysed along with a summary of UTRA-TDD. The adjacent channel protection factor firstly needs to be defined to solve for ACS. It is as follows:

$$ACP^i = \frac{I_{total}^{\ i}}{Prx^i(\frac{pg}{Eb/No} + 1 - M) - \eta} \quad (1)$$

where ACP^i is the adjacent channel protection level required to satisfy the required Eb/No at the i^{th} MS in a cell of interest (COI), Prx^i is the desired signal power, M is the number of users in the COI and η is thermal noise. Pg is the processing gain and $I_{total}^{\ i}$ is defined for UTRA-TDD as:

$$I_{total}(TDD) = \sum_{j=1}^{H}\sum_{i=1}^{M} \alpha \frac{P^j tx_i}{\kappa^j{}_{M_i M_m}} + \sum_{j=1}^{H}(1-\alpha)\frac{Ptx^j M^j}{\kappa^j{}_{B_m}} \quad (2)$$

where $\kappa^j{}_{B_m}$ is the path loss between the j^{th} adjacent channel BS causing interference and the mobile located at m in the COI. M^j is the number of users served by the j^{th} BS. Ptx^j is the j^{th} adjacent BS transmission power. $\kappa^j{}_{M_i M_m}$ is the path loss between the i^{th} MS in the j^{th} adjacent channel cell causing interference and the mobile m in the COI. $P^j tx_i$ is the MS transmission power and α is the synchronisation factor. $I_{total}^{\ i}$ for UTRA-FDD is similar to (2) excluding MS→MS ACI. This results in an α of zero (100 percent synchronisation).

$$I_{total}(FDD) = \sum_{j=1}^{H}\frac{Ptx^j M^j}{\kappa^j{}_{B_m}} \quad (3)$$

The ACS depends on the Adjacent Channel Leakage Ratio (ACLR) as well as the ACP requirement. The ACLR is the ratio of the transmitted interference power to the power measured after a receiver filter in the +/-5MHz offset. The amount of interference in the desired channel coming from adjacent channel interferers cannot be filtered at the receiver. Both the transmitted power and the received power are measured with a root raised cosine (RRC) channel filter with roll-off α = 0.22 and a bandwidth equal to the chip rate. The relationships have been investigated in [3,4] and it is found that:

$$ACS^i = \frac{1}{\frac{1}{ACP^i} - \frac{1}{ACLR}} \quad (4)$$

The cell topology presented in Figure 3 is applied. The distance between the COI (shaded cell) BS and the immediate adjacent channel BS along the a axis is 50 meters. Parameters used in this work are presented in Table I. The layer of interfering hexagon cells was approximated with seven cells as it was found that beyond these cells the caused interference was insignificant [3]. The BSs were located in the center of the cells.

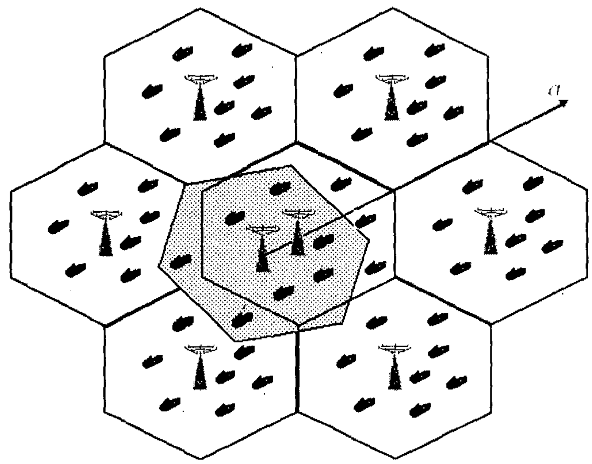

Figure 3. Simulated Cell Topology

TABLE I: SIMULATION PARAMETERS USED.

Parameter	*Value*
Bit Rate	16 Kbits/s
Max TX Power (dBm)	Downlink: 10, Uplink: 4
Thermal Noise (dBm)	-102.85
Required Eb/No (dB)	3.5
Receiver Sensitivity	-112.89
Lognormal Shadowing variable σ (dB)	12
Cell Radius (m)	100
# of Interfering Adjacent Cells	7
# of users in each Interfering Adjacent Cell	8
Synchronisation factor α (TDD mode only)	0.5
Path loss exponent γ	3.0

III. STATISTICAL ANALYSIS

Users in the COI and adjacent channel cells were placed randomly using a uniform distribution. Monte Carlo simulations were then carried out to obtain the cumulative distribution function (CDF) of the ACS powers for TDD and FDD at each random point. In addition, the CDF of the filter lengths for the two duplex modes is presented. The results obtained are for a near full load of eight users in each of the seven adjacent channel interfering cells and a near full load in the COI.

A lognormal shadowing variable of 12dB was used in the simulation. An α *of* 0.5 was used for TDD which leads to 50 percent of ACI from adjacent BSs and 50 percent from adjacent MSs. ACI was found to be similar over the cell area in the COI excluding the area near the immediate interfering base station. In this area, interference is extreme and requires a greater ACS level to satisfy the Eb/No requirement.

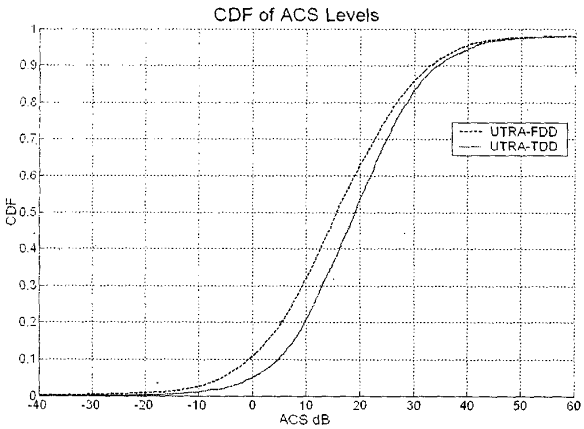

Figure 4. CDF of ACS for UTRA-TDD/FDD

Figure 4 presents the CDF of ACS levels for TDD and FDD. It is clear from this figure that the mean ACS for TDD is 19dB and is 16.26dB for FDD. The 2.74dB difference in the mean concludes that TDD requires 1.87 times the filtering power in the adjacent channel than FDD to satisfy the Eb/No. This is due to the fact that TDD mode has an addition of MS→MS ACI. Depending on the random placement of the adjacent MSs, they can cause severe ACI if next to the MS in the COI. The tails of the CDF show that there is a low probability of high ACS values and also a low probability of low ACS values. It is also noticeable that there cannot be 100 percent cell coverage (right tail of CDF) due to the ACLR resulting in a 7 percent outage.

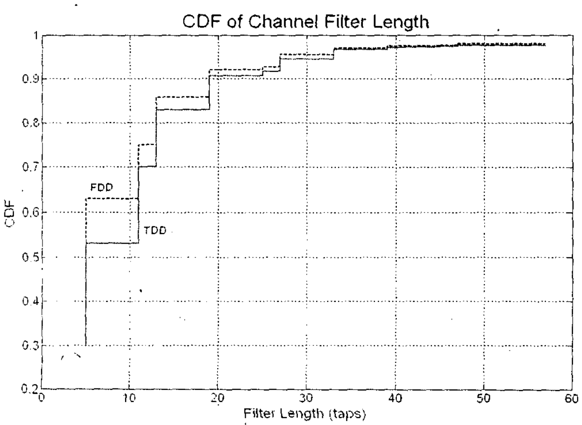

Figure 5. CDF of filter lengths for UTRA-TDD/FDD

Figure 5 illustrates the CDF of filter lengths for TDD and FDD. Decreasing the filter length will decrease the ACS and power dissipation accordingly. TDD mode on average requires 11 taps to satisfy the Eb/No whereas the FDD mode requires 7 taps corresponding to a 75 and 82 percent reduction respectively compared to the specifications [5, 6] where 41 taps is required (33dB ACP). This will prolong talk and standby times in the mobile.

IV. Channel Filter

This section of this document describes the digital channel filter in detail. The architecture is similar to that in [7] however consists of an additional components and is described below. The filter is a digital pulse-shaping low pass filter (LPF) with an impulse response $RC_0(t)$ given by:

$$RC_0(t) = \frac{\sin\left(\pi \frac{t}{T_C}(1-\alpha)\right) + 4\alpha \frac{t}{T_C}\cos\left(\pi \frac{t}{T_C}(1+\alpha)\right)}{\pi \frac{t}{T_C}\left(1-\left(4\alpha \frac{t}{T_C}\right)^2\right)} \quad (5)$$

where the roll-off factor α = 0.22 a bandwidth equal to the chip-rate of 3.84Mc/s. The chip duration is 1/chip-rate. The sampling frequency is 15.36MHz as the chip rate is over sampled by a factor of four. The channel filter architecture is presented in Figure 6. It consists of a direct form finite impulse response (FIR) structure where the output of the filter is a decimated convolution of the input and its coefficients. The novel components that allow the filter to scale its filter length are a high-pass filter (subtraction operation) to obtain the out-of-band signal, three full-wave rectifiers, the three low pass filters to compute a running average and a control unit.

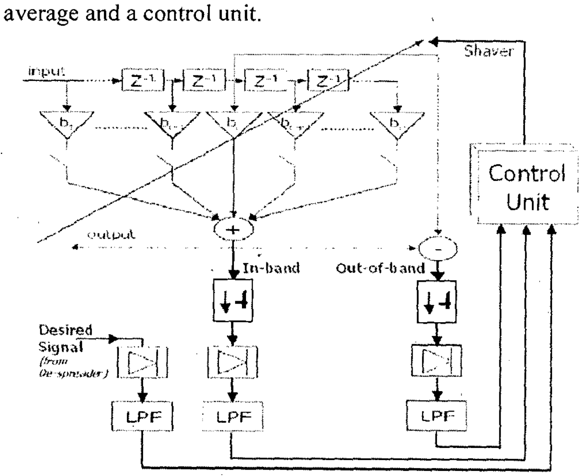

Figure 6. Channel filter with a scalable filter length

The running average LPF's are not complex and have a first order infinite impulse response (IIR) where only two additions and two multiplications are required in hardware.

The output of the filter is the *in-band* signal (desired and co-channel) and the *desired* signal is obtained from de-spread component in the receiver. The control unit is the intelligence behind the architecture. It calculates the appropriate filter length based on the three signals by calculating the required ACS dB. The controller then adjusts the filter length with the *shaver* signal. This signal adds or subtracts taps to the ends of the impulse response and is defined as:

$$shaver = \frac{Max_{flength} - New_{flength}}{2} \qquad (6)$$

where $Max_{flength}$ is the maximum filter length available and $New_{flength}$ is the new calculated filter length. For example, if $New_{flength}$ is 19 and $Max_{flength}$ is 65, *shaver* is set to 23. Therefore, 23 taps from each end of the impulse response will be switched off and the other will be switched on.

The architecture was implemented as an application specific integrated circuit (ASIC), except the control unit, and a performance analysis was carried out on the architecture to ensure it meets the timing requirement (sampling frequency of 15.36MHz) as well as low power requirements. The analysis was carried out in Synopsys Design Compiler and it is clear that the specifications are met. Table II presents the recorded attributes.

TABLE II: ASIC SPECIFICATIONS

Parameter	*Value*
Core Supply Voltage	1.62 V
Maximum Clock Frequency	22MHz
Critical Path	45.11nsec
Synthesis Libraries	Synopsys DesignWare

The dominating factor for power consumption of a digital filter is the multiplier. Therefore, the power consumption should increase with a linear response as the filter length increases. It is clear from Figure 7 that as the filter length increases, the power consumption increases in a linear fashion. For a filter length of 5, the power consumption is 340μW excluding the control unit and for a length of 65, it is 2.56mW excluding the control unit. Figure 8 presents a statistical analysis of the dynamic power consumption with respect to both duplex modes of UTRA.

The average power consumption for UTRA-FDD is 400uW excluding the control unit. It is slightly higher for UTRA-TDD as MS→MS ACI exists. Average 560uW dynamic power consumption has been recorded excluding the control unit.

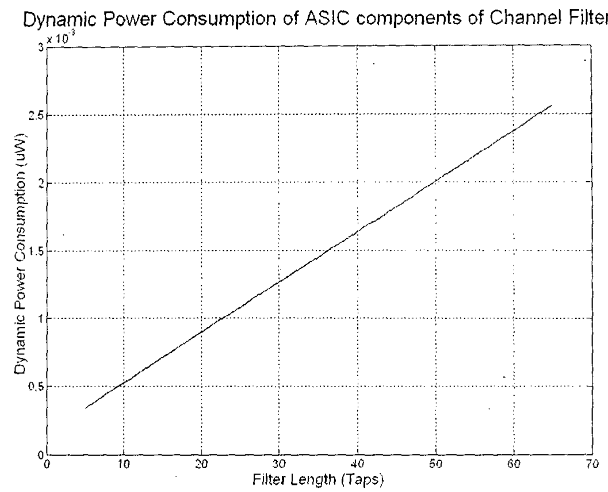

Figure 7. Dynamic Power Consumption of channel filter (ex Control Unit)

The control unit will be implemented on a DSP as it exhibits flexibility. This is desirable as the control code can be modified to suit many platforms.

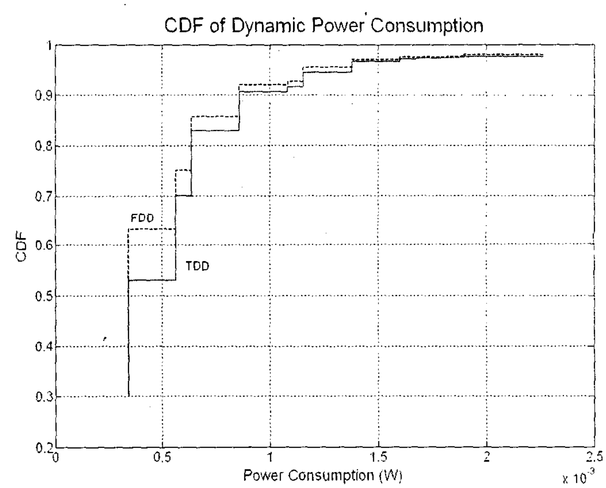

Figure 8. CDF of Dynamic Power Consumption of channel filter for UTRA-TDD/FDD (ex Control Unit)

V. CONCLUSION

A statistical analysis of ACS factors for an UTRA-TDD/FDD mobile terminal receiver was presented. A variable ACS channel filter was also described and analysed. UTRA-TDD has an average ACS of 19dB corresponding to an average filter length of 11 taps. It is 75 percent more efficient compared to the specification ACS of 33dB, which corresponds to an average filter length of 41. UTRA-FDD has an average ACS of 16.26dB corresponding to an average filter length of 11 taps. This is a greater efficiency improvement of 82 percent compared to the specification. The analysis also presented that TDD mode requires 1.87 times the filtering power of FDD due to its near-far problem.

The analysis clearly demonstrated that a receiver channel filter with a variable ACS in the mobile terminal is highly efficient compared to a fixed ACS filter that meets the specifications. This will prolong talk and standby times in an UTRA-TDD/FDD mobile.

A few assumptions have been made. Handover was not assumed, therefore mobiles were allocated to base stations based on minimum distance. Handover may reduce the amount of ACI experienced resulting in lower ACS levels. In addition, the same bit rate for each user was assumed and a time slot was fully loaded by eight users. Variable bit rates and variable users may reduce the amount of ACI.

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