Transmitting Data at 2 Mbps in TD-SCDMA with Multiple Transmit Adaptive Antennas

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Abstract

The work presented in this paper aims at evaluating the 2 Mbps data service (without channel coding) in the 1.28 Mcps TDD option for UMTS technology using the Transmit Adaptive Antennas (TxAA) algorithm. The 2Mbps service is used in indoor propagation environments for downlink (DL) transmissions, from the Base Station (BS) to the User Equipment (UE). There is only 1 receive antenna at the UE and 1, 2, 4 or 8 transmit antennas at the BS to perform either a classical transmission or the Transmit Adaptive Antennas algorithm as a closed loop transmit diversity scheme for dedicated channels. The Minimum Mean Square Error Block Linear Equaliser (MMSE-BLE) is used at the UE as Joint Detection (JD) solution for retrieving data.

1. Introduction

UMTS (Universal Mobile Telecommunications System) is a system that is capable of providing a variety of mobile services to a wide range of global mobile communication standards. It operates at a new 2 GHz frequency band, identified for use by 3G systems at the World Radio Conference in 1992. It works with two different modes chosen at the end of 1997. The first mode, W-CDMA, is a Frequency Division Duplex (FDD) mode. This is a pure Direct Sequence CDMA system, with the information spread over approximately 5MHz bandwidth. The second one is a Time Division Duplex (TDD) mode, called TD-CDMA that is a mixed TDMA and CDMA systems.

The TDD mode of the UMTS is sub-divided into two options, TD-CDMA operating at 3.84 Mcps and TD-SCDMA at 1.28 Mcps, also known as the Narrow-Band TDD option or the low chip rate TDD option. The first option is the historical European TD-CDMA mode, [1] or [2], chosen at the same time as W-CDMA in 1997. The second option was proposed by the China Wireless Telecommunications Standard (CWTS) more recently. The data rate and the bandwidth of TD-SCDMA is one third of those used in TD-CDMA.

Both modes of UMTS can use 2 transmit antennas at the BS side for closed loop and open loop transmit diversity schemes for dedicated channels as well as for common control channels [6], [7]. Transmit diversity schemes for the TDD mode are more specifically described in [3] and [4]. In the 1.28 Mcps TDD option standard the use of antenna arrays at the Base Station (BS) side with at least 8 elements is recommended for implementing beam-forming solutions. The implementation of 8 antennas at the BS, as it is suggested in the Chinese proposal [8], increases the DSP complexity in the BS. A solution for this problem of high complexity may be to change the JD receiver for a Matched Filter (MF), which did not present significant difference in terms of performance in any particular scenarios when at least 4 antennas are used [10] in slowly varying environments. In this context, the impact of different numbers of antennas at the BS side for the 2 Mbps data service in downlink for the 1.28 Mcps TDD option was studied and results, with 1, 2, 4 and 8 antennas, using TxAA [5], are presented in this paper.

In section 2, physical layer characteristics for NB-TDD option are summarised. Then, in section 3, TxAA principles are reviewed, followed in section 4 by simulation assumptions. For this downlink 2 Mbps data service, results are shown in section 5, with a multi-user detector in the UE and a variable number of transmit antennas, from 1 to 8, implementing TxAA.

2. Introduction of the 1.28 Mcps TDD option

The frame structure of TD-SCDMA differs from the frame structure of TD-CDMA in the following way. Both options use a 10 ms radio frame. This radio frame contains 15 time slots (TS) in the 3.84 Mcps option while this 10 ms radio frame is divided into 2 sub-frames of 5ms each in TD-SCDMA. The structure of each sub-frame is the same. The sub-frame is divided into 7 traffic slots (864 chip per timeslot at the chip rate 1.28 Mcps) and 2 special pilot sequences, the downlink pilot (DwPTS) and the up-link pilot (UpPTS), are placed between TS number 0 and 1 in every sub-frame, for synchronisation and beam-forming purposes. The frame structure is depicted in Figures 1 and the sub-frame structure in Figure 2. Due to the particular sub-frame structure, TS 0 is a mandatory DL TS and TS 1 a mandatory UL TS.

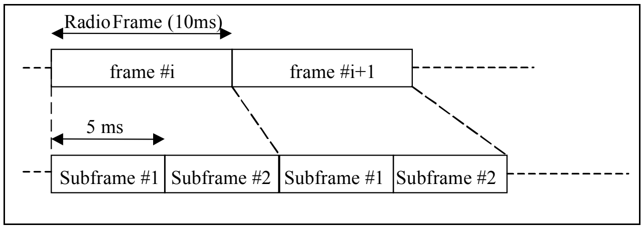

Figure 1: Frame structure of the 1.28 Mcps TDD option

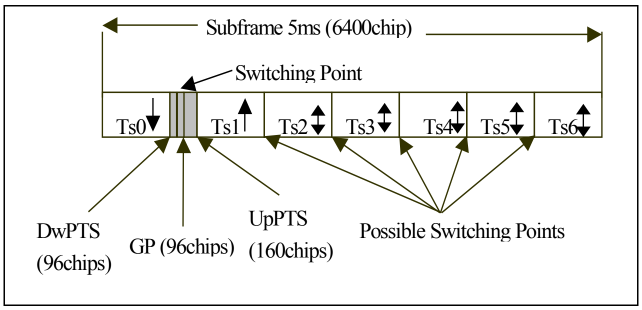

Figure 2: Sub-frame structure of the 1.28 Mcps option

The table below summarises briefly main physical layer parameters for NB-TDD option (see [8] for further details).

Mode	**NB-TDD**
Chip rate	1.28 Mcps
Modulation	QPSK and 8PSK
Spreading factor	1/2/4/8/16
Bandwidth	1.6 MHz
Multi-carrier	Yes
Frame length	10 ms (+2 subframes)
Sub-frame length	5 ms
# of Timeslots	14
Timeslot duration	675 µs
Trafic Burst Formats	1 burst type
Midamble length	144 chips
Multi-user Detection	Optional
Adaptive Antennas	Mandatory
Downlink pilot slot	Yes
Uplink pilot slot	Yes
Variable bit rate	Supported
Service mapping	Multicode and multi-slot combiantion

Table 1: Main characteristics of NB-TDD option.

Characteristics of the 2 Mbps data service will be presented in section 4 when simulation assumptions are discussed.

3. Transmit Adaptive Antennas (TxAA)

TxAA was originally specified for the FDD mode of UMTS and then adapted to the TDD mode [3]. The main difference between these two modes is that, in the FDD mode, the UE has to send TxAA weights to the BS via a feedback channel. For the TDD mode the feedback mechanism is not needed since uplink and downlink frequency bands coincide. The BS indeed can assume that uplink and downlink propagation channels are identical, provided that the uplink and downlink channel reciprocity assumption is made. TxAA weights are calculated by using uplink channel estimates and are applied for downlink. However, TxAA in the TDD context is also a Closed Loop (CL) transmit diversity solution because it uses estimated uplink Channel Impulse Responses (CIR) in order to apply complex valued scalar corrections derived from these estimated uplink CIR for downlink transmissions.

The principle of TxAA is to maximize the Signal to Noise Ratio (SNR), at the receiver level, at the output of the matched filter of the user of interest.

The way TxAA works is shown in Figure 3, in the particular case of two transmitting antennas. Dedicated channels are transmitted coherently with the same data and code at each transmission antenna, but with antenna-specific amplitude and phase weighting. The Mobile Station (MS) uses dedicated midambles (Training Sequences) to estimate downlink propagation channels.

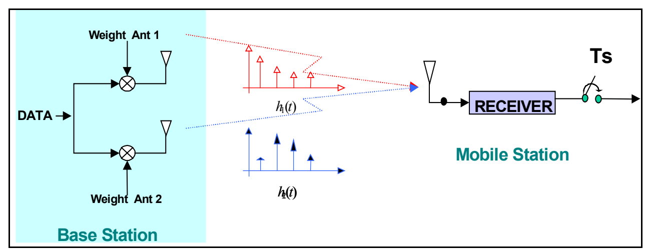

Figure 3: Transmit Adaptive Antennas

In this analysis, perfect channel knowledge and perfect channel reciprocity are assumed. Hence, the estimated channel impulse response ($\boldsymbol{h}_i$) and weight vectors ($\boldsymbol{w}_i$) for the ith transmission antenna are:

$$\hat{\mathbf{h}}_i(t) = \mathbf{h}_i(t)$$
$$\hat{\mathbf{w}}_i(t) = \mathbf{w}_i(t).$$

For each antenna, a column vector represents the CIR. The entries of each of these vectors represent the coefficients of the corresponding discrete-time CIR.

Consider the TxAA scheme with N antennas. Let the spread and modulated Dedicated Physical Data Channel (DPDCH) signal of the user of interest be represented by *d(t)*. Dropping the time reference t for notational convenience, the informative component of the signal received at the MS antenna (noiseless case) at each path delay is then given by:

$$\mathbf{y} = [\mathbf{h}_1 \quad \mathbf{h}_2 \cdots \mathbf{h}_N] \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_N \end{bmatrix} \mathbf{d} = \mathbf{Hwd}.$$

An ideal Maximum Received Power matched filter receiver combines these paths by applying the following coefficients:

$$\mathbf{v} = \frac{\mathbf{w}^H \mathbf{H}^H}{\sqrt{\mathbf{w}^H \mathbf{H}^H \mathbf{H} \ \mathbf{w}}}.$$

These coefficients are normalized so that the noise plus interference level, in the output of the conventional matched filter receiver, does not depend on these coefficients. The output of the receiver can thus be represented as:

$$\mathbf{z} = \mathbf{vy} = \sqrt{\mathbf{w}^H \mathbf{H}^H \mathbf{H} \ \mathbf{w}} \ \mathbf{d}$$

Assuming that the power of d is normalized, the instantaneous received power of the desired signal is given by:

$$P = \mathbf{w}^H \mathbf{H}^H \mathbf{H} \ \mathbf{w} \ .$$

For TxAA the weight vector (**w**) is chosen in order to maximize P, under the unitary norm constraint ($\mathbf{w}^H \mathbf{w} \ = 1$) so that the total transmitted power is normalized. The minimax theorem [9] was used in the particular case that every coefficient can be modified. Finally, the optimum vector is given by:

$$\mathbf{w}_{\mathbf{o}} = \mathbf{x}_{\mathbf{max}}$$

where $\mathbf{x}_{\mathbf{max}}$ is the eigenvector associated with the maximum eigenvalue λ_M of the matrix $\mathbf{H}^H \mathbf{H}$.

4. Simulation assumptions for the 2 Mbps downlink data service

Simulation assumptions detailed in this section correspond to the 2Mbps downlink data service. There is only 1 receive antenna at the UE and 1, 2, 4 or 8 transmit antennas at the BS to perform either a classical transmission or TxAA as closed loop adaptive transmit diversity scheme.
This 2 Mbps data service is only used in some particular environments, such as indoor environments, or in low mobility pico-cellular networks. In this context, a slowly varying indoor scenario was considered and simulations have been run in the Indoor A environment (ETRIA) [12], at a speed of 3 km/h, using the Jakes Model [11] for generating propagation channels. Uncorrelated antenna elements have been considered, assuming a distance between adjacent elements large enough to have uncorrelated propagation channels. A linear antenna array was simulated instead of the circular array proposed in [8].

Regarding the 2 Mbps data service, no channel coding is used and data is modulated with the 8PSK modulation scheme. There is only one active user to which radio resources are massively allocated. It uses 80 physical channels with one physical channel defined as a channelisation code in one time slot in both sub-frames, i.e. 16 channelisation codes in 5 DL time slots in both sub-frames, with a spreading factor equal to 16. In [8], this downlink 2 Mbps data service is proposed with a unitary spreading factor that is more precise and less complex to equalize in reception. For convenience, 16 codes within 5 TS with a spreading factor equal to 16 have been simulated instead.

Uplink joint channel estimations were performed, with an UL Eb/No equal to 6dB. We have assumed that the UL slot (TS #1) is immediately followed by the 5 DL slots (TS #2 to 6). The range of time separation between the UL channel estimations used for DL transmissions is from 675 µs for TS # 2 to 3,375 ms for TS # 6.

The receiver implements a Minimum Mean Square Error Block Linear Equaliser (MMSE-BLE) for doing multi user detection.

5. Performance Results

Simulation results for the 2 Mbps downlink data service, with 1, 2, 4 and 8 transmit antennas at the BS to perform either a classical transmission or TxAA as a closed loop transmit diversity scheme are presented in this section. Data is modulated with the 8PSK modulation scheme.

Performance expressed in terms of raw Bit Error Rate (BER) as a function of the Eb / No ratio are illustrated in Figure 4 for different numbers of transmit antennas.

This 2 Mbps service is an uncoded downlink data service, and at least, as every data transfer, a BER equal to 10^{-5} must be targeted.

Performance of the 2Mbps data service becomes interesting in a scenario with at least 4 antennas. It appears clearly that with a single antenna or even with two transmit antennas that the targeted BER level may be unreachable. This is particularly true if a MF is substituted to the JD for reducing the receiver complexity.

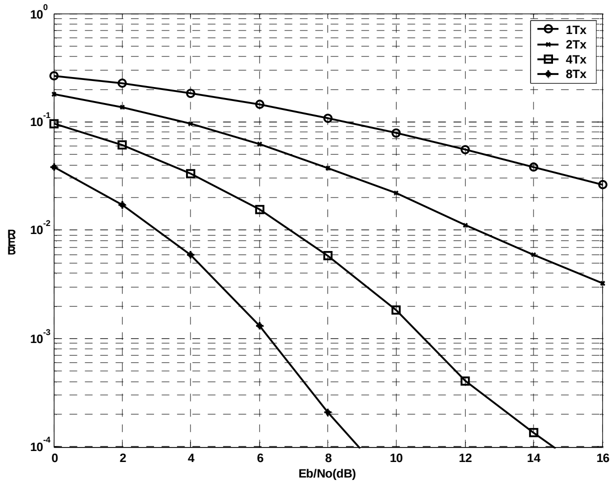

Figure 4: 2 Mbps data service in ETRIA.

Correlation properties between antennas of the array are not taken into account and these results are optimal. In a real scenario, because of space limitations at the base station site, the uncorrelation assumption between elements would be no longer realistic and the global system performance would be degraded, unless correlation properties are efficiently managed.

6. Conclusion

In this paper, the performance of the uncoded 2 Mbps downlink data service in the 1.28 Mcps TDD option of the UMTS was presented, with up to 8 antennas for doing the Transmit Adaptive Antennas (TxAA) algorithm. In specific scenarios, like in indoor environments with a low mobility, TxAA can be seen as a viable solution, though results provided in this paper do not take into account correlation properties between sensors.

The complexity of the receiver may become affordable if a matched filter is substituted by the joint detection receiver. For doing so, at least 4 transmit antennas have to be used.

In terms of radio resources management, this service requires almost every radio resources be allocated to a single user, with 10 time slots among 12 possibly allocated to the downlink are reserved for an un-spread single user, which may be sparsely feasible. When allowed for high-speed downlink data transfers, no multiple access interference would be generated and using a matched filter does make sense.

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