Closed Loop Transmit Diversity Enhancements for UMTS Narrow Band and Wide Band TD-CDMA

Mário Jeronimo DA SILVA, Arnauld TAFFIN, Samson LASAULCE and Soodesh BULJORE
Motorola Labs, Centre de Recherche de Motorola - Paris
Espace Technologique de Saint-Aubin, 91193 Gif-sur-Yvette Cedex, France

Abstract

The aim of the work presented in this paper is to evaluate the performance gains obtained by using multiple transmit antennas at the Node B in the context of the low chip rate TDD option (1.28 Mcps TDD option) being specified in 3GPP RAN WG1. Moreover, the existing high chip rate system (3.84 Mcps TDD option) is also considered as reference. The impact of using multiple transmit antennas at the Node B on the different type of receivers, namely Joint Detection schemes and conventional Matched Filter, in several propagation environments, for a voice-like service (without channel coding) is characterized. Through simulation results, it is shown that, depending on the number of transmit antennas, it may be possible not to implement a Multiuser Detection scheme at the Mobile Station side in TDD mode based systems.

1. Introduction

The second mode of the UMTS, known as the TDD mode, which stands for Time Division Duplex, comprises now two options, the 3.84 Mcps and the 1.28 Mcps options (also known as the Wide Band and the Narrow Band TDD options). The first one, which is the historical European TDD option [1, 2], was chosen at the same time as the W-CDMA mode. The 1.28 Mcps option, proposed by China Wireless Telecommunications Standard (CWTS) within 3GPP TSG RAN WG1, was accepted as second option during year 2000. Due to its particular interest, and because of its technology characteristics, this second option was investigated in order to determine its feasibility and application field.

The 1.28 Mcps TDD option standard recommends the use of antenna arrays at the Base Station (BS) side with at least 8 elements for a beam-forming purpose (e.g. a circular array with 8 elements is recommended in [8]). The 3.84 Mcps TDD option already allows us to 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 [4], [5], [7]. In this paper the impact of using different numbers of antennas at the BS side (downlink case) for both TDD options is studied. Simulation results, with 2, 4 and 8 antennas, using the

closed loop adaptive transmit diversity solution (TxAA) [5], are provided.

One key issue of this study is the receiver architecture. The TDD mode was designed in order to perform Multi-User Detection (MUD) at both sides of the system, leading to a huge computational complexity, especially at the User equipment (UE) side. Therefore, in the presented study, the system behavior is characterized by two different receivers, a Minimum Mean Square Error Block Linear Joint Detector (MMSE-BLE) and a Matched Filter (MF) implementing the Rake receiver, in order to know in which cases a MUD is needed for achieving aimed performance for speech like service.

The paper is organized as follows. First, in section 1, we give a brief summary of the two different TDD options at the physical layer level. In section 2, we review the TxAA principles and design criteria that correspond to maximizing the Signal to Noise Ratio (SNR) at the output of the conventional matched filter for the user of interest. Simulation assumptions are presented in section 3. The receiver architecture is studied in section 4, depending on the number of transmit antennas, 2, 4 and 8, in downlink, for both TDD options. The related simulation results are given and discussed.

2. Differences between both TDD options

The differences are mainly located at the physical layer level, such as the frame structure, the number of antennas, the use of smart antennas algorithms or the modulation scheme. The table below summarizes briefly main physical layer parameters for both TDD options.

Mode	NB-TDD	WB-TDD
Chip rate	1.28 Mcps	3.84 Mcps
Modulation	QPSK and 8PSK	QPSK
Spreading factor	1/2/4/8/16	1/2/4/8/16
Bandwidth	1.6 MHz	5 MHz
Multi-carrier	Yes	No
Frame length	10 ms (+2 subframes)	10 ms
Sub-frame length	5 ms	No
Number of timeslots	14	15
Timeslot duration	675 μ s	666.67 μ s
Traffic Burst Formats	1 burst type	2 burst types
Midamble length	144 chips	256/512 chips

Multi-user Detection	Optional	Optional, but required
Adaptive Antennas	Mandatory	Optional
Downlink pilot slot	Yes	No
Uplink pilot slot	Yes	No
Variable bit rate	Supported	Supported
Service mapping	Multicode and multi-slot combination	Multicode and multi-slot combination

Table 1: Main characteristics of both TDD options

Differences mainly concern the frame structure, depicted in Figures 2 and 3 below.

Figure 2: Frame structure of the 3.84 Mcps option

Figure 3: Sub-frame structure of the 1.28 Mcps option

For the 3.84 Mcps TDD option, the frame duration is 10 ms, and the frame is composed of 15 time slots (TS) of equal duration, i.e. 666.67 μ s, corresponding to 2560 chip durations.

The 1.28 Mcps TDD option is also based on a 10 ms frame structure, but the radio frame is divided into two sub-frames of 5 ms each. Each sub-frame contains 7 normal traffic TS of 675 μ s each, corresponding to 864 chip durations.

The main difference between both options is the presence of a downlink pilot and an uplink pilot between the first and the second TS of each sub-frame.

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 as 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. The principle of TxAA is to maximize the Signal to Noise Ratio (SNR), at the receiver level, in the output of the matched filter of the user of interest. 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 way TxAA works is shown in Figure 1, 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 1: Transmit Adaptive Antennas

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

$$\begin{aligned}\hat{h}_i(t) &= h_i(t) \\ \hat{w}_i(t) &= w_i(t).\end{aligned}$$

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 DPCH 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:

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

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:

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

Assuming that the power of $\mathbf{d}$ 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 ($\mathbf{w}$) 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:

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

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

4. Simulation Assumptions

Simulations assumptions detailed in this section correspond to a typical un-coded speech service only. Downlink transmissions from the Node B to the UE were considered. There is only 1 receiving antenna at the UE and 1, 2, 4 or 8 transmit antennas at the Node B to perform either a classical transmission or transmissions with TxAA as closed loop transmit diversity scheme for dedicated channels as described in section 3.

A QPSK modulation is assumed. There are 8 active users per time slot, each of them using a single channelisation code (Orthogonal Variable Spreading Factor: OVSF) with a spreading factor equal to 16 and a dedicated midamble sequence.

A 10 ms frame structure for both options is considered. The 5 ms sub-frame structure was not taken into account for the 1.28 Mcps TDD option, i.e. both downlink and uplink pilots were not introduced in the sub-frame structure. Indeed, in

the case of uncoded link level simulations without beamforming, it has a negligible effect on our link level performance assessment (due to the use of a single physical channel, i.e. a single code in a single time slot, every 10 ms). Perfect synchronizations (carrier and burst detections) and inter systems interference mitigations are considered.

Two commonly used ITU propagation models are considered: the Indoor A channel (ETRIA), which is nearly a flat fading channel, and the Pedestrian B channel (ETRPB), which is characterized by a high frequency selectivity. For both propagation channels, the mobile speed is fixed at 3 km/h, which corresponds to a pedestrian speed. For this speed, using one time slot per frame instead of using one time slot per sub-frame has no significant impact on performance obtained for the 1.28 Mcps option.

In the uplink, channel estimations are performed at a fixed signal to noise ratio ($E_b/N_0 = 6$ dB). In the downlink, channel estimates are normally obtained which means that the channel estimates accuracy depends on the noise level. The whole channel estimates (e.g. 57 chips in the WB-TDD uplink) were accounted for in detectors.

A multi-switching points frame structure was considered (symmetrical traffic assumption) where an UL slot is immediately followed by a DL slot which is immediately followed by an other UL slot and so on. It means that the time difference between the UL channel estimations used for DL transmissions is 666.67 μ s for the WB-TDD option and 675 μ s for the NB-TDD option, that is the best possible case for using closed loop transmit diversity schemes such as TxAA.

There is no correlation between signals in DL. The spacing between two adjacent sensors is assumed to be large enough to ensure this non-correlation property.

Behaviors of two different receivers, a Minimum Mean Square Error Block Linear Joint Detector (MMSE-BLE) and a simple Matched Filter (MF) implementing a Rake receiver have been compared for all simulations except those without transmit diversity for which, only the MMSE-BLE has been considered.

5. Simulation Results

Simulations results with 2 and 8 antennas using the closed loop TxAA transmit diversity algorithm are presented in sections 5.1 and 5.2 respectively. Finally, a comparison between performance achieved with a conventional Matched Filter (a Rake receiver in the multipath case) and an MMSE-BLE receiver for both TDD options is made. Results corresponding to the cases where 2, 4 and 8 antenna elements are assumed are summarized in Tables 2 and 3 in sections 5.3 and 5.4 respectively.

5.1 Performance with 2 antennas in transmission

Figure 4: NB-TDD vs. WB-TDD in ETRIA with 2 transmitting antennas.

Figure 5: NB-TDD vs. WB-TDD in ETRPB with 2 transmitting antennas.

With 2 transmit antennas performing TxAA it can be observed that in the ETRIA environment, the degradation due to the use of Rake receiver instead of a MUD receiver could be considered as negligible.

This is not the case in the ETRPB environment where the frequency selectivity of propagation channels is a key parameter. In such a case, an error floor is reached with a matched filter, for both options. It is obvious that with only 2 transmit antennas the UE needs a MUD to remove the Multiple Access Interference (MAI) in order to achieve acceptable performance.

Performance results of both options are very similar in general, whatever the environment (ETRIA and ETRPB) and the receiver (MMSE-BLE and MF) are.

5.2 Performance with 8 antennas in transmission

Figure 6: NB-TDD vs. WB-TDD in ETRIA with 8 transmitting antennas.

Figure 7: NB-TDD vs. WB-TDD in ETRPB with 8 transmitting antennas.

With 8 antennas, the NB-TDD option performs much better than the WB-TDD option, in every tested propagation environment, with both receivers. Intuitively, this can be explained by the fact that, at 1.28 Mcps, propagation channels are less frequency selective than at 3.84 Mcps, leading to a smaller number of rays. Thus, TxAA works better at 1.28 Mcps than at 3.84 Mcps, in the sense that TxAA complex valued scalar corrections applied on signals prior to emission compensate better multipath propagation channels experienced at 1.28 Mcps than at 3.84 Mcps, because of the smaller frequency selectivity of propagation channels.

When analyzing the behavior of both receivers, it appears that, when 8 transmit antennas are used, performances are very close to each other, for both TDD options, even in an

highly frequency selective environment such as the ETRPB. The equivalent channel viewed from the UE of interest (the summation of the 8 weighted CIR), is such that the MAI is less severe and impacting than when a smaller number of antennas is used. The Rake receiver draws more benefits from this particularity. As a consequence, a Rake receiver works as well as a MUD receiver in the downlink, as it can be seen in Table 2, since, the main difference between both receivers is that a MUD combats the MAI and not a Rake receiver.

5.3 Rake and MMSE-BLE receivers performance

Eb/No(MF) – Eb/No(MMSE) @ BER = 2%		Type of mode	
Number of sensors	Environment	WB	NB
1	Indoor A	***	***
1	Pedestrian B	***	***
2	Indoor A	+ 0.8 dB	+ 0.4 dB
2	Pedestrian B	+ 6 dB	+ 3.5 dB
4	Indoor A	+ 0.2 dB	+ 0.15 dB
4	Pedestrian B	+ 2 dB	+ 0.6 dB
8	Indoor A	≈ 0 dB	+ 0.2 dB
8	Pedestrian B	+ 0.5 dB	+ 0.2 dB

Table 2: Rake versus MMSE-BLE

5.4 Comparison between both TDD options

Eb/No(WB) – Eb/No(NB) @ BER = 2%		Type of receiver	
Number of sensors	Environment	MF	MMSE
1	Indoor A	***	- 0.6 dB
1	Pedestrian B	***	- 1.4 dB
2	Indoor A	+ 1 dB	+ 0.8 dB
2	Pedestrian B	+ 3 dB	≈ 0 dB
4	Indoor A	+ 0.5 dB	+ 0.4 dB
4	Pedestrian B	+ 2.5 dB	+ 1.2 dB
8	Indoor A	+ 1 dB	+ 1.2 dB
8	Pedestrian B	+ 2 dB	+ 1.8 dB

Table 3: Comparison between both TDD options

It can be seen, from Table 3, that when the number of transmitting antenna elements is greater or equal to 4 the 1.28 Mcps option works better than the 3.84 Mcps option.

6. Conclusion

In this paper, a comparison between physical layer performances of the two TDD options of the 3GPP UMTS standard obtained with different number of transmitting antennas at the Node B is presented. The 1.28 Mcps TDD option has shown better (or equal) performance than the 3.84 Mcps TDD option when at least 2 transmit antennas

are used. This is interpreted by the frequency selectivity, which is smaller in the 1.28 Mcps case, leading to a more accurate TxAA solution for this option than for the other one. It is also important to note that the Rake and the MUD MMSE receivers tend to perform equally as the number of sensors increases. This observation holds not only for nearly flat channels (only one significant path) but also for frequency selective channels (real multipath case). When more than 4 sensors are used, the Rake receiver performs almost as well as a receiver using Multiuser Detection.

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