On the Network Performance of UTRA-like TDD and FDD CDMA Systems Using Adaptive Modulation and Adaptive Beamforming

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Abstract

In this contribution we characterise the capacity of an adaptive modulation assisted, beam-steering aided TDD/CDMA system. In TDD/CDMA the mobiles suffer from interference inflicted by the other mobile stations (MSs) both in the reference cell the MS is roaming in (intracell interference) as well as due to those in the neighbouring cells (intercell interference). Furthermore, in contrast to FDD/CDMA, where the Base Stations (BSs) transmit in an orthogonal frequency band, in TDD/CDMA there is additional interference imposed by other BSs of the adjacent cells, since all times-slots can be used in both the uplink and downlink. In return for this disadvantage, TDD/CDMA guarantees the flexible utilization of all the available bandwidth, which meets the demand for the support of asymmetric uplink and downlink services, such as high data rate file download in mobile Internet services, etc. In wireless systems the link quality fluctuates due to either fading- and dispersion-induced channel impairments or as a consequence of the time-variant co-channel interference imposed by the teletraffic fluctuations due to the varying number of users supported. Due to these impairments conventional wireless systems often drop the call. By contrast, a particular advantage of employing adaptive modulation is that the transceiver is capable of automatically reconfiguring itself in a more error-resilient transmission mode, instead of dropping the call. This contribution studies the achievable network performance by simulation and compares it to that of the FDD/UTRA system.

1. INTRODUCTION

The third generation mobile communication systems such as the Universal Mobile Telecommunication System [1] (UMTS) have been designed for supporting various types of services, such as video telephony [2], fax, wireless Internet, etc. All these services require flexible and efficient resource allocation methods. The IMT-2000 standard comprises two types of air-interfaces, namely FDD/CDMA and TDD/CDMA [2]. In the latter scheme, the uplink and downlink transmissions are time multiplexed on different timeslots of the same carrier, while in FDD/CDMA the uplink and downlink transmissions occur in different frequency bands [3, 4, 5, 6, 1]. The advantage of TDD/CDMA is that it is capable of accommodating diverse asymmetric and variable-rate services, such as multimedia applications, Internet browsing and file transfer, etc [7, 8, 9], which is facilitated by assigning different number of timeslots in the up and downlinks. A further benefit of TDD/CDMA is the similar nature of the channel in the uplink and downlink, since the corresponding bursts are transmitted at the same frequency. This can be advantageously exploited for open loop power control and transmission diversity assisted pre-RAKE techniques [9], which can reduce the complexity of the MS. Furthermore, adaptive antennas or beam-forming [1] as well as multiuser detection are more likely to be implemented in TDD/CDMA cellular scenarios, since on average the number of active MSs in every slot is reduced, which reduces the complexity. The employment of beam-forming [1] is expected to lead to a further increased system capacity. In recent years research interests in the evaluation of the capacity of the FDD/CDMA systems [1] have intensified. By contrast, there is a paucity of contributions on the capacity analysis of TDD/CDMA in cellular environments. Hence in this contribution we analyse the capacity of TDD/CDMA cellular systems.

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2. INTERFERENCE SCENARIO IN TDD/CDMA

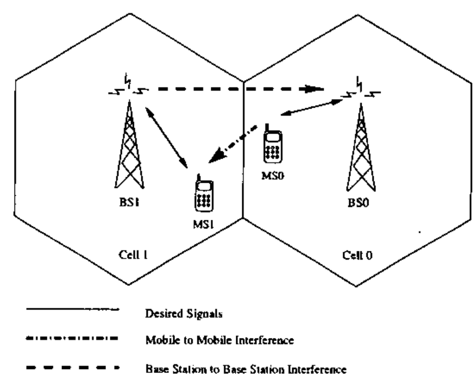

Figure 1: Inter-cell interference.

TDD is attractive in terms of facilitating the allocation of asymmetric or uneven resources to the uplink and downlink, which supports a more efficient exploitation of the frequency bands available. However, the associated interference scenario is markedly different from that experienced in FDD, as shown in Figure 1.

Mobile to mobile (MS-to-MS) interference occurs in the situation displayed in Figure 1, if MS_1 is transmitting, while MS_0 is receiving in a specific timeslot mapped to the same carrier frequency in an adjacent cell. The MS-to-MS interference cannot be completely avoided

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Parameter	Value	Parameter	Value
Noisefloor	-100dBm	Pilot power	-5dBm
Frame length	10ms	Cell radius	150m
Multiple access	TDD/CDMA	Number of basestations	49
Modulation scheme	4QAM/QPSK	Spreading factor	16
Minimum BS transmit power	-44dBm	Minimum MS transmit power	-44dBm
Maximum BS transmit power	21dBm	Maximum MS transmit power	21dBm
Power control stepsize	1dB	Power control hysteresis	1dB
Low quality access (0.5 % BER) SINR	7.0dB	Outage (1% BER) SINR	6.6dB
Pathloss exponent	-3.5	Size of Active Basestation Set (ABS)	2
Average inter-call-time	300s	Max. new-call queue-time	5s
Average call length	60s	Pedestrian speed	3mph
Maximum consecutive outages	5	Signal bandwidth	5MHz
Target SINR (at BER=0.1%)	8.0 dB		

Table 1: Simulation parameters.

by network planning, since the geographic location of mobiles cannot be controlled.

TDD/CDMA is also prone to base station (BS-to-BS) interference. In fact, as it will be shown later, it is the most serious source of intercell interference in a TDD/CDMA cellular scenario. As seen in Figure 1, if BS_1 is transmitting and BS_0 is receiving at the same time in a given timeslot, BS-to-BS interference takes place, provided that these base stations are in adjacent cells. The severity of the BS-to-BS interference depends heavily on the path loss between the two base stations, hence it can be reduced with the aid of careful network planning.

3. SYSTEM PARAMETERS

New call channel allocation requests were placed in a resource allocation queue for up to 5s. If during this period a call was not serviced, it was classed as blocked. The mobiles moved freely, in random directions, at a speed of 30mph within the simulation area, which consisted of 49 cells. The cell-radius was 150m. The call duration and inter-call periods were Poisson distributed with the mean values shown in Table 1. For our initial investigations we have assumed that the basestations and mobiles form a synchronous network, both in the up- and the down-link and all the time frames in the cells are equally divided into uplink slots and downlink slots, which means that all cells have the same half/half UL/DL pattern.

Furthermore, the basestations are assumed to be equipped with the Minimum Mean Squared Error Block Decision Feedback Equaliser (MMSE-BDFE) based Multi-User Detector (MUD) [14]. The post despreading SINRs required by this MUD for obtaining the target BERs were determined with the aid of physical-layer simulations using a 4-QAM modulation scheme, in conjunction with $1/2$ rate turbo coding and MUD for transmission over a COST 207 seven-path Bad Urban channel [15]. Using this turbo-coded MUD-assisted transceiver and a spreading factor of 16, the post-de-spreading SINR required for maintaining the target BER of 1×10^{-3} was 8.0 dB. The BER which was deemed to correspond to low-quality access, was stipulated at 5×10^{-3}. This BER was exceeded for SINRs falling below 7.0dB. Furthermore, a low-quality outage was declared, when the BER of 1×10^{-2} was exceeded, which was encountered for SINRs below 6.6 dB. These values can be seen along with the other system parameters in Table 1.

4. PERFORMANCE METRICS

There are several performance metrics that can be used for quantifying the performance or quality of service provided by a mobile cellular network. The following performance metrics have been widely used in the literature and were also advocated by Chuang [13]:

- New call blocking probability, P_B.
- Call dropping or forced termination probability, P_{FT}. A call is dropped when the lower of the uplink and downlink SINRs dips consecutively below the outage SINR (5% BER) a given number of times.
- Probability of a low quality access, P_{low}, quantifies the chances of either the uplink or downlink signal quality being sufficiently poor, resulting in a low quality access (1% BER).
- Probability of outage, P_{out}, is defined as the probability that the SINR is below the value at which the call is deemed to be in outage.
- Grade-Of-Service (GOS) was defined by Cheng and Chuang [13] as :

$$\begin{aligned} GOS &= P\{\text{unsuccessful or low-quality call accesses}\} \\ &= P\{\text{call is blocked}\} + P\{\text{call is admitted}\} \times \\ &\quad P\{\text{low signal quality and call is admitted}\} \\ &= P_B + (1 - P_B)P_{low}. \end{aligned} \quad (1)$$

5. SIMULATION RESULTS

In [10] we analytically studied the achievable network performance of UTRA-like TDD/CDMA systems, where conventional fixed-mode modulation was assumed. By contrast, in [1] the performance of a UTRA-like FDD/CDMA system was quantified, when supported by adaptive beam-steering and adaptive modulation [11, 12]. These performance improvements have approximately doubled the network capacity of the system.

Our current research is building on our previous findings recorded in the context of a UTRA-like FDD system [1], where we found that invoking adaptive modulation as well as beam-steering proved to be a powerful means of enhancing the capacity of FDD/CDMA. Hence they are expected to be even more powerful in the context of TDD/CDMA, where the capacity of TDD/CDMA is poor as a consequence of the excessive basestation-basestation interference experienced.

The advanced UTRA FDD system level simulator [1] employing adaptive antenna arrays at the basestation was extended to the UTRA TDD mode for evaluating the system achievable performance. We observed quite significant performance gains as a direct result of the interference rejection capabilities of the adaptive antenna arrays invoked. Network performance results were obtained using two and four element adaptive antenna arrays, both in the absence of shadow fading, and in the presence of 0.5 Hz and 1.0 Hz frequency shadow fading exhibiting a standard deviation of 3 dB. The adaptive beamforming algorithm used was the Sample Matrix Inversion (SMI) algorithm. The specific adaptive beamforming implementation used in our TDD/CDMA based network was identical to that used in the network simulations of [1]. Briefly, one of the eight possible 8-bit BPSK reference signals was used for identifying the desired user, while the remaining interfering users were assigned the other seven 8-bit reference signals. The received signal's autocorrelation matrix was then calculated, and from the knowledge of the desired user's reference signal the receiver's optimal antenna array weights were determined with the aid of the SMI algorithm. This implementation of the algorithm only calculated the receiver's antenna array weights, i.e. the antenna array weights used by the base station for receiving the mobiles' uplink transmissions. However, it was demonstrated in [1] that further performance gains are attainable, if the UL and DL array pattern are optimised individually. The antenna array weights were recalculated for every power control step, i.e. 15 times per UTRA data frame, owing to the potential significant changes in terms of the desired signal and interference powers that may occur during one UTRA frame as a result of the maximum possible 15 dB change in the power transmitted by each user.

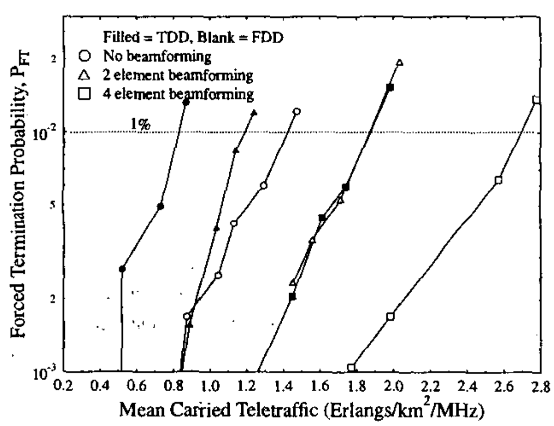

Figure 2: Call dropping probability versus mean carried traffic of the UTRA-like TDD/CDMA based cellular network of Table 1 both **with as well as without beamforming and without shadowing** for SF=16.

Figure 2 shows the call dropping probability associated with a variety of traffic loads without shadowing, measured in terms of the mean normalised carried traffic expressed in Erlangs/km^2/MHz. The figure suggests that the network's performance was poor without employing antenna arrays at the base stations. The "No beamforming" scenario suffered from the highest call dropping probability of the three traffic scenarios at a given load. When using "2 element beamforming", the adaptive antenna arrays have considerably reduced the levels of interference, leading to a reduced call dropping probability. Without employing antenna arrays at the base stations the network capacity was limited to 142 users, or to a teletraffic load of approximately 0.81 Erlangs/km^2/MHz. However, with the advent of employing two-element adaptive antenna arrays at the base stations the number of users supported by the network increased by 45% to 206 users, or almost to 1.18 Erlangs/km^2/MHz. Replacing the two-element adaptive antenna arrays with four-element arrays led to a further capacity increase of 56%, or 127% with respect to the capacity of the network using no antenna arrays. This is associated with a network capacity of 322 users, or 1.85 Erlangs/km^2/MHz. We can also see in Figure 2 that the capacity of the UTRA-like TDD/CDMA cellular system is poorer than that of the UTRA-like FDD/CDMA system under the same propagation conditions. The "TDD 4 element beamforming" senario has a similar performance to the "FDD 2 element beamforming" senario. This is because the TDD system suffers from the effects of the extra inter-cell interference, which we alluded to in Section 2.

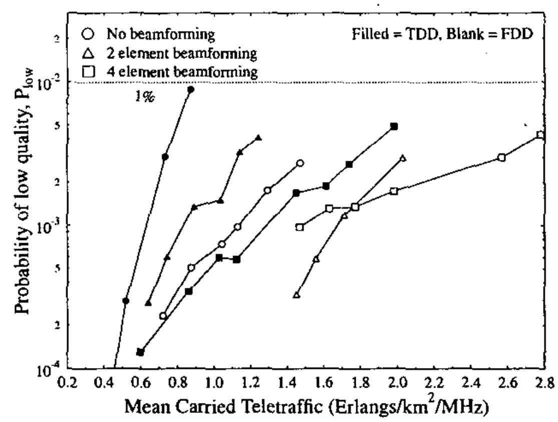

Figure 3: Probability of low quality access versus mean carried traffic of the UTRA-like TDD/ CDMA based cellular network both **with as well as without beamforming and without shadowing** for SF=16.

Figure 3 portrays the probability of low quality access versus various traffic loads. Again, it can be seen from the figure that higher traffic loads were carried with the aid of the four-element array at a sufficiently low probability of a low quality, than that achieved using a two-element array.

Figure 4 shows the achievable Grade-Of-Service (GOS) for a range of teletraffic loads. Similar trends were observed regarding the probabiliy of call blocking to those shown in Figure 2. The grade of service is better (i.e.,lower) when the traffice load is low, and vice versa for high traffic loads. This is mainly attributable to the higher call blocking probability of the "No beamforming" scenario, particularly in the region of the highest traffic loads.

The impact of adaptive antenna arrays recorded in a propagation environment subjected to shadow fading was then investigated. The associated call dropping performance is shown in Figure 5. This figure illustrates the substantial network capacity gains achieved with the aid of both two- and four-element adaptive antenna arrays under shadow fading propagation conditions. Simulations were conducted in conjunction with log-normal shadow fading having a standard deviation of 3 dB, experiencing maximum shadowing frequencies of both 0.5 Hz and 1.0 Hz. As expected, the network capacity was reduced at the higher shadow fading frequency. Without employing

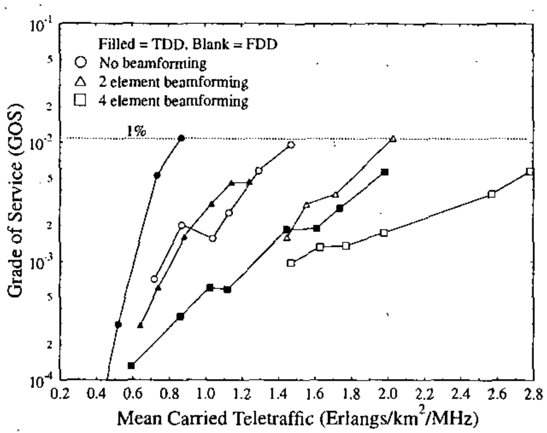

Figure 4: Grade-Of-Service (GOS) versus mean carried traffic of the UTRA-like TDD/CDMA based cellular network both **with as well as without beamforming and without shadowing** for SF=16.

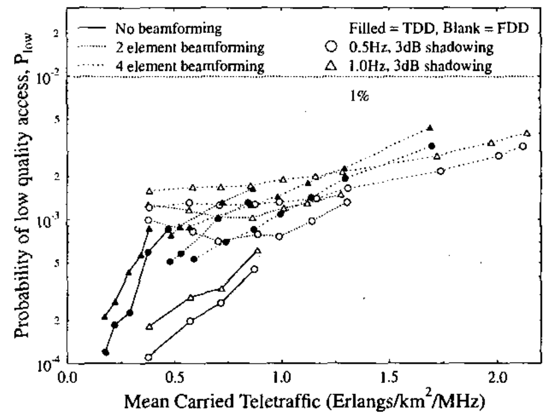

Figure 6: Probability of low quality access versus mean carried traffic of the UTRA-like TDD/CDMA based cellular network both **with as well as without beamforming and with shadowing** for SF=16.

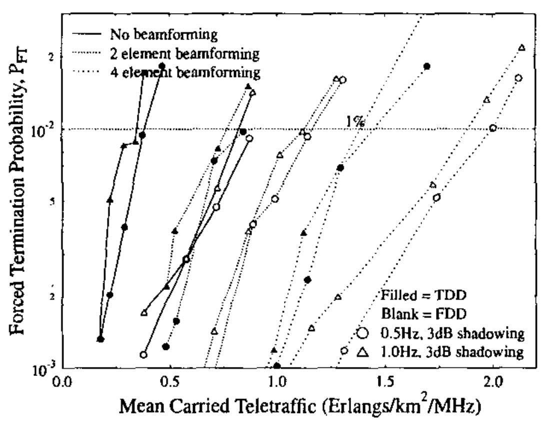

Figure 5: Call dropping probability versus mean carried traffic of the UTRA-like TDD/CDMA based cellular network both **with as well as without beamforming and with shadowing** for SF=16.

adaptive antenna arrays, the network supported just over 71 users and 62 users, when subjected to 0.5 Hz and 1.0 Hz frequency shadow fading, respectively. With the application of two-element adaptive antenna arrays, these capacities increased by 111% and 113%, to 151 users and 131 users, respectively. The employment of four-element adaptive antenna arrays led to a network capacity of 245 users at a 0.5 Hz shadowing frequency, and 234 users at a 1.0 Hz shadowing frequency. This corresponded to relative gains of 62% and 78% over the capacity provided with the aid of two-element adaptive antenna arrays.

The probability of low quality access performance is depicted in Figure 6. As expected, a given P_{low} value was associated with a higher traffic load, as the number of antenna elements increased. When the maximum shadow fading frequency was increased from 0.5 Hz to 1.0 Hz, P_{low} also increased. The probability of low quality seen in Figure 6 is similar in the senarios employing adaptive antenna arrays in the UTRA TDD and FDD CDMA systems. It should be noted, however that the probability of low quality access always remained below the 1% constraint of the conservative scenario under the scenarios studied, and the call dropping probability was considerably reduced by the adaptive antenna arrays, as it is seen in Figure 7.

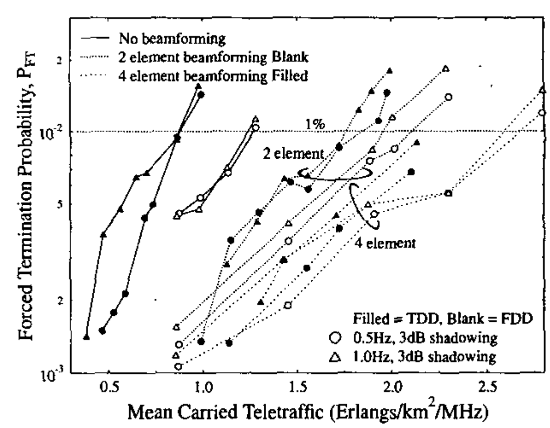

Figure 7: Call dropping probability versus mean carried traffic of the UTRA-like TDD/CDMA based cellular network both **with and without beamforming in conjunction with AQAM as well as with shadowing having a standard deviation of 3 dB** for SF=16.

More explicitly, Figure 7 shows the significant reduction in the probability of a dropped call, achieved by employing adaptive antenna arrays in conjunction with adaptive modulation [1, 11, 12] in a log-normal shadow faded environment. The figure demonstrates that, even with the aid of a two-element adaptive antenna array, a substantial call dropping probability reduction was achieved. The single-antenna based network was found to support 153 users, corresponding

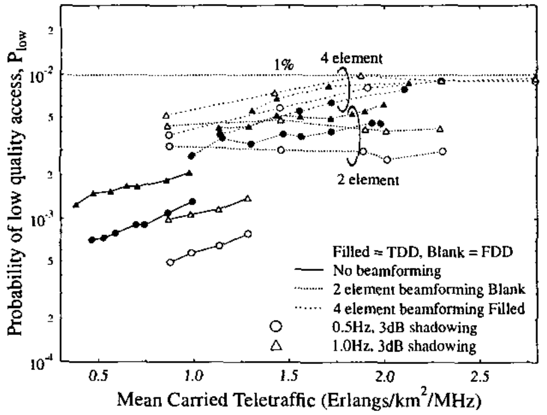

Figure 8: Probability of low quality access versus mean carried traffic of the UTRA TDD/CDMA based cellular network both **with and without beamforming in conjunction with AQAM as well as with shadowing having a standard deviation of 3dB** for SF=16.

to a traffic load of 0.875 Erlang/km^2/MHz, when subjected to 0.5 Hz frequency shadow fading. The capacity of the single-antenna aided network was slightly reduced to 152 users, or 0.874 Erlang/km^2/MHz, upon increasing the maximum shadow fading frequency to 1.0 Hz. Upon employing two-element adaptive antenna arrays, the network capacity increased by 109% to 320 users, or to an equivalent traffic load of 1.834 Erlang/km^2/MHz, when subjected to 0.5 Hz frequency shadow fading. When the maximum shadow fading frequency was increased to 1.0 Hz, the number of users supported by the network was 307, or 1.82 Erlang/km^2/MHz, representing an increase of 102% in comparison to the network refraining from using adaptive antenna arrays. It is seen in Figure 7 that the forced termination probability of the UTRA-like TDD/CDMA senarios is close to that of the FDD/CDMA senarios, when employing adaptive antenna arrays in conjunction of with adaptive modulation.

The probability of low quality outage, presented in Figure 8, did not benefit from the application of adaptive antenna arrays, in fact on the contrary. Furthermore, recall that Figure 6 depicted the probability of low quality outage without adaptive modulation, i.e. using fixed modulation, and upon comparing these results to those obtained in conjunction with adaptive modulation shown in Figure 8, the performance degradation owing to the employment of adaptive modulation can be explicitly seen. This is because the increase in the probability of low quality access can be attributed to the employment of less robust, but higher throughput, higher-order modulation modes invoked by the adaptive modulation scheme. Hence, under given propagation conditions and using the interference-resilient fixed 4-QAM modulation mode, as in Figure 6, a low quality outage may not occur. By contrast, when using adaptive modulation invoking a less resilient, but higher-throughput and higher-order modulation mode, the same propagation conditions may inflict a low quality outage.

6. SUMMARY AND CONCLUSIONS

The network performance of the UTRA TDD system was investigated. The benefits of adaptive atenna arrays and adaptive modulation techniques on the UTRA TDD network's capacity was considered in both non-shadowed and log-normal shadow-faded propagation environments. In conclusion, the employment of adaptive arrays in conjunction with AQAM limited the detrimental effects of co-channel interference and resulted in performance improvements both in terms of the achievable call quality and the system's capacity.

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