Performance of Dynamic Timeslot-Code Assignment Strategies in UTRA-TDD

Tallal Elshabrawy, Tho Le-Ngoc

Department of ECE, McGill University, 3480 University, Montréal, Québec, Canada H3A 2A7

telsha@po-box.mcgill.ca, tho@ece.mcgill.ca

Abstract — This paper presents various dynamic Timeslot-Code Assignment (TCA) strategies, using heuristic rules or online measured information, suitable to support real-time multimedia services in UTRA-TDD. In the measurement-aided TCA scheme employing minimum instantaneous power (MIP) criterion, the base station assigns resources to an active burst in the timeslot where the corresponding mobile terminal will transmit minimum power to meet a target signal to interference and noise ratio (SINR). A self-corrective (SC) strategy used with the MIP scheme is introduced to adapt to interference variations during burst transmission. The satisfied user criterion is used as a metric to assess the system capacity. Simulations using OPNET for both speech and streaming video services are presented. Simulation results show that the SC-MIP outperforms the other simple TCA schemes.

I. INTRODUCTION

Universal Mobile Telecommunications System (UMTS) depicts the standardization efforts for third-generation (3G) wireless mobile communication systems within 3GPP [1]. Services extend over those currently supported by second-generation (2G) systems to include interactive multimedia high data rate services, such as video streaming, data, pictures and web, etc. at rates up to 2Mb/s. Wideband CDMA (WCDMA) has been chosen as the main radio-access technology. The UMTS proposal includes two modes: Frequency-Division Duplex (FDD) and Time-Division Duplex (TDD). This paper focuses on the UMTS Terrestrial Radio Access (UTRA) TDD mode. In TDD, uplink and downlink channels share the same frequency. Each frame is divided into 15 timeslots. Each timeslot is dedicated for uplink or downlink and can support up to 16 OVFS codes with a spreading factor of 16 [2]. The access scheme is known as TD-CDMA and resources are defined in terms of timeslot-code units.

With high bandwidth demands and stringent Quality-of-Service (QoS) requirements of 3G bearer services, Radio Resource Management (RRM) aims to achieve high efficiency in resource utility while guaranteeing satisfaction of users by using dynamic resource allocation. In general, dynamic resource allocation in UTRA-TDD could be divided into a three-step operation as follows:

Step 1: Capacity Allocation (CA):

This step deals with the allocation of resource units to the admitted sessions. For efficient use of the available resources, CA distributes shared resources among *active bursts* with the objective of satisfying QoS requirements constrained to available capacity of the system. CA is also responsible of the queue management especially for

non-real time services and decides which mobile terminals with active bursts may compete for wireless resources at any instant.

Step 2: Timeslot-Code Assignment (TCA):

Based on the capacity allocation, the particular timeslots and OVFS codes (i.e., spreading factors) are assigned to each admitted session to satisfy its burst allocated rate and SINR requirements.

Step 3: Power Allocation (PA):

Transmitted power at each terminal is allocated over the timeslots in each TDD frame in accordance with total power availability and power control requirements.

CDMA is known to be interference-limited and therefore TCA becomes the key dynamic resource allocation component in order to increase the system capacity while maintaining the required user satisfaction. TCA in UTRA-TDD attempts to arrange scheduled terminal transmissions over system timeslots in the most efficient manner that benefits from time diversity between slots.

In this paper, we investigate dynamic timeslot-code assignment strategies supporting real-time multimedia services in the uplink direction. We define simple heuristic TCA strategies and compare those with a proposed measurement-aided TCA scheme termed Minimum Instantaneous Power (MIP). In MIP, the base station assigns resources to an active burst in the timeslot where the corresponding mobile terminal will transmit minimum power to meet a target signal to interference and noise ratio (SINR). For speech services TCA operates in a burst-driven manner where the TCA assigns resource to traffic sources only during activity periods. This is shown to enhance system capacity over circuit-switched allocation proposed for other investigations addressing UTRA-TDD [3], [4]. TCA for video streaming services is applied periodically to ensure maintaining session quality during the connection interval. CA is assumed to follow a simple First-Come-First Serve (FCFS) strategy and PA is considered such that mobile transmission power over each timeslot does not exceed $T_{\max}$.

The rest of the paper is organized as follows. In Section II, we discuss the various TCA schemes. In Section III, we describe the simulation models while, in Section IV, we present simulation network. In Section V we discuss simulation results. Finally in Section VI, we conclude and discuss future work.

II. TIMESLOT-CODE ASSIGNMENT (TCA) SCHEMES:

We consider two classes of TCA schemes. Simple TCA schemes apply heuristic rules to map mobile terminals' bursts to wireless resource units. Measurement-aided schemes on the other hand use online measurements information to help in the TCA decision. In essence, the choice between simple and measurement-aided schemes is a compromise between complexity and performance. Simple schemes avoid the sophistication of online measurement and processing of interference data and follow simple rules. However, given the information input available to measurement-aided schemes, superior performance should be expected as a compromise for the associated complexity. In the next sub-sections we introduce different TCA schemes proposed in this paper.

A. Simple TCA Schemes:

A.1. Spread over Low-Load TS (SoL):

Given a mobile terminal scheduled for a number of resource units, SoL will assign resources in an incremental fashion (i.e., one resource unit after the other) over the timeslot currently supporting the minimum number of resource units. In other words, for a terminal requiring K resource units, the SoL will search K times for the timeslot with the minimum number of assigned resource units and use that for the resource unit in question. The intuitive reasoning of such heuristic scheme is to balance interference generated by each cell.

A.2. Concentrated in High-Load TS (CiH):

The CiH attempts to assign all scheduled resources units belonging to an active burst on the timeslot with maximum number of already assigned resource units. If available resources on the selected timeslot are not enough to support the mobile terminal request, the CiH will search for the next timeslot in terms of high resource units' concentration. The procedure is repeated until all scheduled resources are assigned. The objective of CiH is to generate un-coordinated timeslot diversity between base stations of the network by minimizing the number of timeslots used within each cell.

A.3. Concentrated in Low-Load TS (CiL):

The CiL is a compromise between the SoL and the CiH where the TCA concentrates resource units requested by an active burst of a given mobile terminal on the same timeslot. However, the timeslot selected for concentration is the one with minimum number of assigned resource units.

B. Measurement-Aided TCA Scheme using Minimum Instantaneous Power (MIP) criterion:

Given a new burst requesting wireless resources, the MIP will probe all timeslots to assess the instantaneous transmitted power requirement for reliable communications and assign the timeslot where the

corresponding transmission power satisfying the target SINR requirement is minimum. The signaling is conducted through pilot signals transmitted at equal power from the mobile towards the serving base station on all timeslots and measuring the corresponding SINR. The timeslot with the maximum SINR is expected for the least transmission power and therefore is selected for assignment. It is important to highlight that, as compared to the simple TCA schemes discussed in Section A, there is some added complexity required to monitor the timeslot status for each terminal before assignment takes place. However, the TCA decision remains distributed.

While MIP shares with some techniques in the previous work such as LIR [3] the objective of selecting the timeslot with minimum interference, the difference between them is in the metric used for the assignment. This will be proven important when we get to the feasibility of applying timeslot re-assignments or self-correction as will be discussed in the next sub-section. Using transmission power as the guidance for assignment provides SINR status feedback embedded in the power control operation without the need of mobile terminals reporting their bit error rate. Another aspect that distinguishes MIP is that it applies burst-driven assignment for speech. LIR proposed in [3] assumes call-driven assignment for speech services and therefore misses potential statistical multiplexing benefits.

C. Self-Corrective Strategies:

The MIP considers only the current status of interference received in the timeslots at the assignment instant. The level of interference received in a timeslot can vary due to new assignments by other base-stations and may deteriorate the performance of its on-going bursts. We consider a self-corrective strategy in attempt to rectify negative effects of interference generated across the network by MIP decisions. This is conducted by re-assigning resources for mobiles suffering from unforeseen interference generated due to subsequent assignments in the network. Previous work such as [3] allows timeslot re-assignment based on bad SINR. In MIP, re-assignment is triggered as part of the power control routine whenever power requirements exceed the power at the disposal of the transmitter. Insufficient transmission power will cause the SINR performance to deteriorate due to:

- High probability that the burst will experience inadequate SINR due to the lack of power
- High generated interference levels
- Other codes at the same transmitting node assigned on that timeslot are lost due to lack of power

A self-corrective strategy may respond to a maximum power requirement event by two possible approaches:

- (i) Do not send (i.e., lose the packet) and wait until desired transmission power decreases

- (ii) Switch to another timeslot in accordance with the MIP TCA strategy

The second approach is adopted in our studies.

III. SIMULATION MODEL

Traffic Models:

Speech service sources are modeled using a two-state ON-OFF model [5]. During the ON-state the source is assumed to generate packet bursts (i.e., M timeslot-code units) at a constant rate. During the OFF-state the source is assumed to be silent. The ON and OFF sojourn periods are both exponential with parameters $1/\beta_{\text{ON}}$ and $1/\beta_{\text{OFF}}$, respectively. Call durations are assumed to be exponential with a mean duration of $1/\mu$.

Based on [6], stream video could be modeled as a fixed rate stream source. The number of resource units required per call depends on the quality of the video session. The session duration is also assumed exponential with mean duration of $1/\mu$.

Call Setup Model:

A new call will select the base-station with the strongest path gain as the serving base-station nominated to be responsible for call management and TCA. Path gain is computed based on large-scale parameters (path loss and shadowing) of a particular base-station towards the desired mobile terminal.

Call Handoff Model:

A base-station will continue to serve a certain mobile terminal as long as it persists to provide the strongest path gain towards that mobile terminal. A handoff otherwise will be triggered and the control of that mobile terminal is transferred to another base-station that currently possesses the strongest path gain. The implemented model assumes that each mobile terminal considers for a handoff opportunity every T_{Handoff} seconds.

Antenna Models:

We consider a Directional Phased Arrays (DPA) model. In the DPA model, we assume a perfect capability of the DPA of tracking the mobile terminal signal such that it is always received at maximum gain. Interference arrival angles are computed relative to the angle of the maximum gain. The assumption of perfect tracking renders an upper bound on the TCA performance employing DPA.

Receiver Performance Model:

The quality of signal received in the system is quantified using the Signal to Interference Noise Ratio (γ). The receiver model implemented is governed by the equation:

$$\gamma_m = \frac{PG \times T_m \times PL_{mj} \times X_{mj} \times A_{mj} \times \left(\sum_{p=1}^P S_{mj}^p \right)}{\sum_i \alpha_{ij} \times T_i \times PL_{ij} \times X_{ij} \times A_{ij} \times \left(\sum_{p=1}^P S_{ij}^p \right) + N} \times \frac{1}{m}$$

where γ_m : SINR at mobile m , PG: processing gain, T_m : transmitted power from mobile m , PL_{mj} : path loss between mobile m and base station j , X_{mj} : shadowing component between mobile m and base station j , A_{mj} : antenna gain between mobile m and base station j , S_{mj}^p : small-scale fading component of the p^{th} path between mobile m and base station j , N : background noise, m : number of bits per symbol, α_{mj} : multi-user detection (MUD) interference rejection coefficient between mobile m and base station j .

$\alpha_{mj} = \alpha$ for intra-cell interferers, $\alpha_{mj} = 1$ for inter-cell interferers.

Packets received with SINR γ_m below a threshold value γ_{th} are considered to be erroneous. Otherwise, they are assumed to be correctly received.

Power Control Model:

We consider a SINR-based power control approach. Every frame the receiver computes the SINR of the received packets(s). The receiver computes the difference between the instantaneous SINR and a target SINR (γ_t) value. The power control model will then use this information to instruct the transmitter to increase/decrease the transmitted power the next frame in order to approach the desired level γ_t .

TCA Models:

For efficient use of communications resources, we propose a burst-driven TCA, in which bearer services are only assigned resources during their ON (i.e., active) periods. As soon as the traffic source moves into the OFF state, it relinquishes the resources assigned. For stream traffic, a time-driven TCA is needed to periodically maintain the quality of connections.

Satisfied User Model:

We use the satisfied user criterion introduced in [5] to assess the performance of each session. As per [5], a user is satisfied if his call:

- does not get blocked,
- has the percentage of lost packets below x_1 %, and
- does not get dropped.

Note that a call is dropped if the packet loss persists for t_d seconds.

In this paper, we assume that calls have been already admitted to the network and therefore only the last two criteria are used to reflect user satisfaction. The network capacity is defined as the load (i.e., number of users per cell) at which the percentage of satisfied users is x_2 %.

IV. SIMULATION NETWORK

We assume a micro-cell corner-excited cellular network with 36 cells as shown in Figure 1. Parameters of the simulated system are presented in Table 1, Table 2, and Table 3. In our simulations, we investigate TCA performance for speech services (12.2 kbps voice service

requiring 2 RU per call during its ON period) [5] and 64 kbps stream video (requesting 5 RU during session time) [7]. The threshold defining a satisfied user x_1 is 5% and the network capacity is assumed when 98% (x_2) of the users are satisfied.

Figure 1: Simulation model of 36 corner-excited cells

Table 1: Cellular Network Parameters

Cell Coverage	Micro-cell
Cell Type	Edge-Excited
Mobile Speed	3 Km/hr
Handoff Interval (T_{Handoff})	1 sec
Frame Duration	10 msec
Simulation Time	360 sec
Call Duration	120 sec
Speech Mean ON Durations (β_{ON})	3 sec
Speech Mean OFF Durations (β_{OFF})	3 sec
Number of Timeslots	6

Table 2: Receiving and Power Control Parameters

Receiving Parameters	MUD coefficient rejection	0.1
	Number of Paths	2
	Noise Figure	5 dB
	Background Noise	-107.01+NF dBm
	SINR Threshold (BER 10^{-3}) (γ_{th})	2.1dB
Power Control Parameters	Target SINR (γ_t)	7.5 dB
	Power Control Step	3 dB
	Max Tx Power	24dBm

Table 3: Large Scale and Small Scale Parameters

Large Scale Parameters	Path Loss Model: Hata Small to Medium City	$PL=137.744+35.225\log_{10}(R_{km})(\text{dB})$	
	Shadowing Model: Simple ARMA model for correlated shadowing	De-correlation length	20 meters
		Correlation Parameter	0.5
		Standard Deviation	10 dB
	Antenna Parameters	Number of Elements	8
Small Scale Parameters	Fading Parameters: Correlated Rayleigh Fading using Jakes' Model[8]	Maximum Gain	$13+10 \log(8) = 22.031 \text{ dBi}$
		Number of Paths	2
		Path power [0]	0 dB
		Path power [1]	-10 dB
		Jakes' number of generators per path	60

V. SIMULATION RESULTS

Figure 2 and Figure 3 show the simulation results on the performance of the proposed TCA schemes in terms of percentage of satisfied users versus average number of active users per cell for speech and streaming services, respectively. SoL offers the best performance among simple TCA schemes. The SoL aims to achieve an equal distribution of assigned resource units over the timeslots. As a result, the amount of interference generated over timeslots of each cell is also balanced. SC-MIP possesses a gain of 15% over MIP, which in turn provides a gain of 37% over SoL for the case of speech services. For video streaming services, the capacity gains of SC-MIP over SoL are more significant due to the higher bandwidth requirements per user (5 resource units/user).

The results clearly show the advantage of a burst-driven TCA in the case of speech services. Note that given 6 timeslots, the capacity per cell is 96 resource units. In a circuit-switched TCA, the system can only admit a maximum of 48 users per cell, while the burst-driven TCA using SC-MIP can support, in average, up to 60 admitted users per cell for 98% satisfied users as shown in Figure 2.

In Figure 4, we present results for a mixed scenario with 50% speech and 50% stream video. The share of each service is computed based on the corresponding resource requirements. Since the voice-to-video average required capacity ratio per session is 1 : 5, the average amounts of voice and video calls are adjusted to 5/6 and 1/6, respectively, in order to achieve a 50%-50% mix. For example when the load in Figure 4 is at 24 users, then on average the number of speech users is 20, while the average number of streaming video users is 4.

Figure 2: TCA Performance Comparison for Speech Services

Figure 3: TCA Performance Comparison for Video Streaming Services

Figure 4: 50% Speech and 50% Stream Video Mix, (i.e., number of speech users/ number of streaming video users =5)

Results indicate that at low load the performance stream video is better than that of speech. However, as the number

of users per cell increases, the speech service starts to outperform that of stream video.

VI. CONCLUSIONS

In this paper, we have considered various dynamic timeslot-code assignment strategies supporting real-time multimedia services in UTRA-TDD and evaluated their performance in terms of percentage of satisfied users versus average number of active users per cell. We have also introduced a self-corrective strategy to further enhance the performance of MIP. By considering the measured power in the allocation, the proposed MIP can provide a much larger system capacity as compared to the other simple TCA schemes. Simulation results also indicate that the introduced self-corrective strategy can further enhance the performance of MIP. In future work, we will examine the performance of the proposed MIP for non-real-time services such as WWW browsing. We will also investigate how queuing can operate in conjunction with MIP to increase system capacity.

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