MANAGEMENT OF CIRCUIT AND PACKET SWITCHED DATA IN UMTS TERRESTRIAL RADIO ACCESS NETWORKS

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Abstract — **This paper describes and evaluates the application of *Radio Resource Management* (RRM) mechanisms within the *UMTS Terrestrial Radio Access Network* (UTRAN) environment. The main focus herein is the *Time Division Duplex* (TDD) mode since it offers the flexibility required by the proposed algorithms. Simulation scenarios and traffic models are discussed. The system performance is evaluated by different combinations of channel allocation, scheduling, multiplexing on shared radio channels, and call admission strategies.**
Keywords — **UMTS, Dynamic Channel Allocation, Quality of Service, Traffic Modeling, Radio Resource Management, Scheduling, Call Admission Control**

I. INTRODUCTION

Established cellular mobile network operators and several newcomers entered the UMTS market recently and invested immense cost and effort to become a licensed participant in the 3G market. The main promise of UMTS is its ability to provide not only speech and simple data communications but also high data rate multimedia services [1].

One of the main tasks for the *UMTS Terrestrial Radio Access Network* (UTRAN) operators is the fair and efficient distribution of their expensively auctioned spectrum to the different groups of users to offer advanced services expected by the future markets. The characteristics of *Code Division Multiple Access* (CDMA) have to be taken into account to achieve optimal spectrum efficiency and system capacity. This paper evaluates the management of the UTRAN resources, so-called *Resource Units* (RU). A single RU represents the combination of one CDMA code in one timeslot at one frequency [2].

The first phase of UMTS based on 3GPP "Release'99" [3] is currently emerging in Japan and provides speech, low data rate Internet and simple data traffic. The increasing demand for multimedia communications will draw the focus on highly flexible systems with a wide range of capabilities to share the allocated spectrum taking into account the asymmetry of the offered services. Whereas speech services can be easily handled by the *Frequency Division Duplex* (FDD) operation mode with symmetric *Uplink* (UL) and *Downlink* (DL) capacity, multimedia data might require the *Time Division Duplex* (TDD) operation of UTRAN to fulfill the various requirements of all connections in each radio cell.

This brings about the need to have intelligent resource control and managing algorithms in UTRAN radio network controllers. This paper describes *Radio Resource Management* (RRM) routines for application in UTRAN. Simulation results of simple strategies for managing voice and data traffic in micro-cellular networks are presented. The remainder is organized as follows. Sec. II introduces RRM mechanisms and their application in UTRAN. In Sec. III the simulation environment and relevant parameters of the traffic models are described. Sec. IV contains simulation results and Sec. V concludes the paper.

II. RADIO RESOURCE MANAGEMENT

RRM describes several ways of controlling and managing the scarce radio resources of a mobile network. In the following, a brief introduction to three basic RRM methods is given. The focus of this paper in the following is the TDD mode of UTRAN.

A. Channel Allocation

In *Fixed Channel Allocation* (FCA) strategies, the channels (or radio resources more general) are assigned fixed to radio cells. Moreover, all radio resources in one cell are supposed to offer the required transmission quality. Careful network planning is mandatory for this purpose. Either available channel in one cell can be assigned to a connection by random selection from the pool of resources and remains fixed until call ending. The system therefore is unable to react flexibly with the varying capacity demand of the users within each cell. There is no mechanism to improve the current transmission quality by rearranging the radio resource allocation. Moreover, FCA cannot assign varying asymmetric capacity to UL or DL transmission since no shifting of the TDD switching point in the radio frame can be handled.

In CDMA mode of UTRAN all users share all available resources simultaneously, which results in a cluster size of one for FCA (all resources are available in each cell). To improve FCA, channel measurements are considered when searching for a new channel so that the *Least Interfered Resource* (LIR) will always be allocated. With this mechanism, a dynamic behavior of channel allocation sets in since resources already in use at neighbouring cells can be identified and remain unused. However, since this state differs in each subsequent radio frame, this basic attempt would affect mostly the beginning of a connection. Simulation results can be found in [4] for a macro-cellular environment and in [5] for the micro-cell urban environment.

One proposed *Dynamic Channel Allocation* (DCA) scheme for UTRAN operates decentralized and bases on interference measuring [6]. In terms of *Quality of Service* (QoS), the DCA tries to guarantee that resources being allocated have appropriate level of interference according to each service type's requirements in order to avoid link failures and keep *Bit Error Ratio* (BER) constraints. Additionally, the DCA is able to reconfigure the allocation in the radio frame so that after elementary changes (e.g. a call ending, handover), resources can be redistributed to other connections where otherwise QoS constraints might be violated.

B. Call Admission Control

To avoid system overloading, an intelligent *Call Admission Control* (CAC) should be applied when a traffic mixture with different call priorities has to be served. UTRAN foresees various types of services initiated by different types of users willing to pay different amounts of money. Hence, differentiated CAC seems appropriate [7].

Two different criteria responsible for the for CAC decision are to be mentioned. Firstly, CAC can operate based on interference measurements. In this context, not only the measurements in the own cell, but also predictions of interference in neighbouring cells are of interest [8]. A new call will be refused by the system if either the interference in the own cell or an interference level in any neighbouring cell exceeds a predefined threshold. Secondly, the criteria for CAC can be derived from the current load situation. Using this strategy, a new call is only admitted to the system if the load at the currently allocated *Base Station* (BS), e.g. the fraction of occupied RU in a UTRA TDD frame, is below a threshold. The two strategies are illustrated in form of flow charts in Fig. 1.

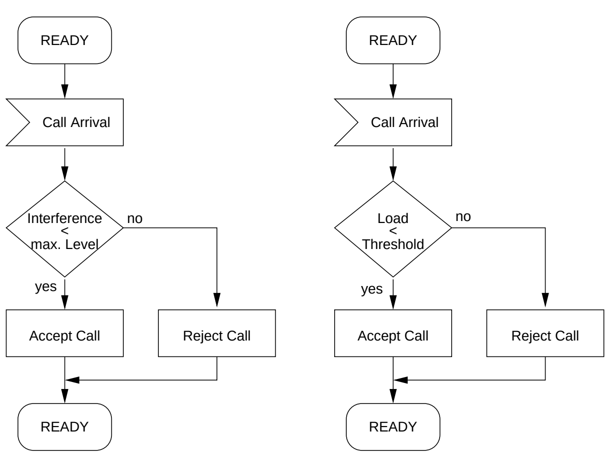

Figure 1: Interference or load based call admission control

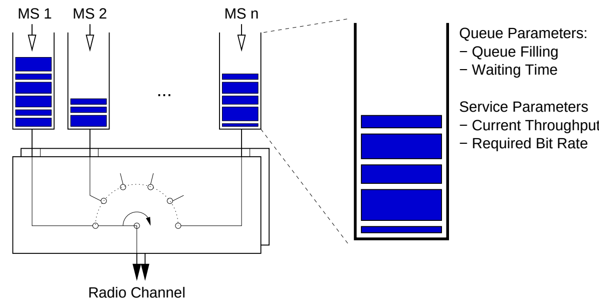

Figure 2: Scheduling with shared radio channels

C. Scheduling

Scheduling algorithms become necessary for packet switched services in communication networks. A schematic overview of a scheduler is illustrated in Fig. 2. This kind of scheduler makes use of the statistical multiplexing gain of shared radio channels. A common channel in the air interface is alternately assigned to different users depending on certain scheduling criteria based on different priorities for the user's data. Furthermore, filling states of queues, waiting times of packets already queued in, or simply a Round Robin algorithm may determine which data stream will be connected to the radio channel [9]. With this method, QoS constraints such as delay or throughput requirements can be fulfilled.

Scheduling along with data processing can be improved to assign multiple scheduler switches to constant sized radio channels or by allowing a variable bit rate transmission by changing the radio channel setting, e.g. the number of RU available on this physical channel. A combination of packet scheduling with DCA can improve throughput and data quality as the best channel is always chosen for the most urgent data packets waiting at the scheduler input.

Hence, the interface between scheduler and channel allocation instance has to be quite close. An allocation request has to be signaled to the channel allocation algorithm as soon as

- the waiting times for packets in all queues exceed a certain delay (taking into account the capacity of the currently allocated channels),
- the throughput per service drops below a threshold.

On the other hand, the shared channels have to be freed as soon as possible if

- the filling state of all queues drops below a certain threshold,
- the throughput per service exceeds a pre-defined limit.

To fairly share the commonly used radio channels, the scheduler should assign the resources to the connection which QoS parameters are the worst. The decision whether a new channel is needed or an allocated channel could be released depends on the overall state of the scheduler input queues.

III. SIMULATION PARAMETERS

Simulation Environments The large simulation scenario is a Manhattan-like urban model [10]. The block size measures 200 m×200 m with streets of width 30 m in between giving a simulation area of 7.142 km^2. In this scenario, the inner six BS are evaluated and the others generate additional traffic and interference in order to have realistic conditions in the center of the scenario. A smaller scenario with only 12 BS is created to examine RRM algorithms more closely and to reduce computational effort. Fig. 3 illustrates the scenario settings.

Propagation Model In the Manhattan scenario, the pathloss calculations fall into three categories. The first case is when there is *Line-Of-Sight* (LOS) between the *Mobile Station* (MS) and its associated BS. Here, the pathloss formula for free space $L = 20 \log \frac{4\pi d}{\lambda}$ is used, where λ is the wavelength of the transmitted radio signal and d the distance between MS and BS.

The second case is when there is one building corner between MS and BS of a *Non-Line-Of-Sight* (NLOS) connection. The recursive formula specified in [10] is used to obtain the pathloss value.

In the last case when there are two corners between MS and BS, a fixed value of 220 dB is assumed for the ease of calculations. The recursive formula can be used for more accuracy in the pathloss value. However, the increase in accuracy does not significantly contribute to the result of the simulation, since the pathloss values for propagation around multiple corners are even higher.

Mobility Model Streets are divided into segments, connected together by intersections. Pedestrians travel along the streets at a velocity of 3 km/h and users in vehicles are considered 30 km/h. When a mobile arrives at an intersection, the probabilities of moving towards a new direction are 50 % forward, 25 % turning right, and 25 % turning left. Along the edges of the scenario, there are 3-way intersections instead of regular 4-way intersections. In this case, the turning probability is set to 50 % for either available continuing road. In the situation where a mobile reaches a corner of the scenario it will proceed on to the other road element connected to that corner.

Radio Parameters Tab. 1 summarizes the basic radio specific parameters concerning the physical layer settings and conditions.

Interference The total of interference originated from all participants within a radio network impairs radio transmission more severely than the background noise. Therefore, systems are evaluated with respect to their current *Signal to Interference Ratio* (SIR) whereby the impact on transmission errors of the two parts–noise and interference–is similar since they are treated as a certain amount of additional uncorrelated noise.

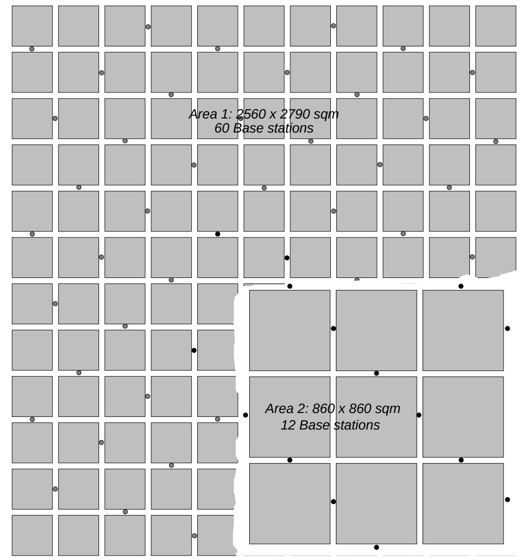

Figure 3: Manhattan-like urban simulation scenarios

Table 1: Radio parameters of simulated UTRA-TDD

Parameter	Value
Frequency	1900-1905 MHz
Transmission chip rate	3.84 Mcps
TDD frame duration	10 ms
Number of time slots	15
Number of codes per slot	16
Spreading factor	16
Modulation	QPSK
Max. BS transmit power	42 dBm
DL dynamic range	20 dB
Max. MS transmit power	36 dBm
UL dynamic range	80 dB
Prop. coefficient	2.0
Min. pathloss	42 dB
Shadowing mean	0 dB
Shadowing std. deviation	10 dB
Background noise	-102 dBm

Power Settings In CDMA systems, *Power Control* (PC) algorithms are mandatory for the operation of radio communications [11]. Nevertheless, joint detection is applied in TDD mode and PC can be seen as a method to reduce inter-cell interference in the network. Since no clustering and thus channel grouping is necessary in CDMA systems, PC greatly improves the system capacity.

Circuit Switched Traffic Source Circuit switched speech connections are characterized by Poisson arrivals of calls with a mean call duration of $t_{D,\text{Speech}} = 120\,\text{s}$. To provide an 8 kbps connection, two RU are needed for each speech connection–one in UL and one in DL.

A speech connection is alternating between active and silent period times (see Fig. 4). Both, active and silent times, are negative exponentially distributed with mean $T_{active} =$

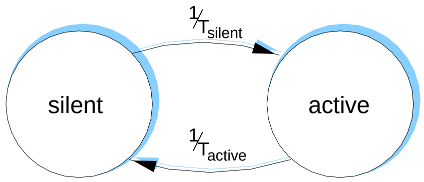

Figure 4: Traffic model for speech service

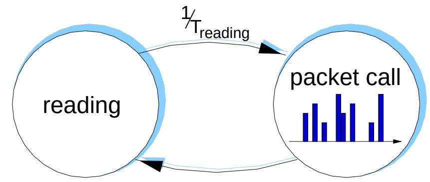

Figure 5: Traffic model for packet data services

$T_{silent} = 3\,s$. This results in a channel activity of 50 %. Each connection carries an amount λ_{Speech} of capacity calculated by

$$\lambda_{\text{Speech}} = \frac{n_{\text{Speech}}}{N}\,, \tag{1}$$

where n_{Speech} is the number of occupied RU per TDD frame. N holds the number of available RU per frame. With 15 timeslots and 16 available codes per timeslot, $N = 240$ for a single carrier frequency with 5 MHz bandwidth. The parameters for speech service are summarized in the second column of Tab. 2.

The traffic will be varied within the simulations in order to find and determine the system capacity limits of RRM schemes by adjusting the inter arrival time. Applying traffic models for the mobiles in which terminals are sometimes active and sometimes silent, leads to time-varying interference situations and capacity demands where hot spot areas occur randomly on arbitrary locations.

Packet Switched Traffic Source UMTS defines multiple packet service classes with a wide range of user bit rates and certain requirements for transmission delay.

Web browsing packet data traffic is characterized to appear during so-called browsing sessions as illustrated in Fig. 5. Session call arrivals are modeled by a Poisson process similar to the arrivals of speech service calls. During a session, several packet call requests will be initiated by the user. The number of packet calls within a session is a geometrically distributed random variable N_{pc} with an average value of $\overline{N}_{pc} = 5$. This means, an average of five packet calls will appear within one session.

The reading time between consecutive packet calls t_{read} is a geometrically distributed random variable with mean $\overline{t}_{read} = 12$ s. After this pause, a new packet call will be initiated. The reading time starts after the packet is completely received and hence, the exact value of t_{read} will be generated after the last transmitted packet is received and triggers the next packet call.

The average requested file size is $\overline{S}_{pc} = 12$ kbyte spread over several packets with a mean amount of 480 byte data. The packets represent elements of web pages requested by the user. However, this model completely neglects signaling and acknowledgment traffic as described in [12] and needs a more detailed implementation for future investigations of packet data traffic.

In an attempt to estimate the requested capacity of a single packet data connection, sessions are considered similar to speech connections. The duration $t_{D,\text{Packet}}$ of a complete session is mainly affected by the reading time between the packet calls. When neglecting the times of the packet call phases, it can be calculated by

$$t_{D,\text{Packet}} \approx (\overline{N}_{pc} - 1) \times \overline{t}_{read}\,. \tag{2}$$

A single RU is able to carry a certain amount of user's data S_{RU}. Following the UMTS specifications [3], this will be approximately 29 byte when spreading with *Spreading Factor* (SF) 16 and when no error correction mechanism is used. The number $\overline{n}_{pc}$ of RU used during one packet call request can be estimated with

$$\overline{n}_{pc} = \frac{\overline{S}_{pc}}{S_{RU}}\,. \tag{3}$$

Furthermore, the overall mean number $\overline{n}_{read}$ of unused RU during one reading time period which also belongs to the session is calculated by

$$\overline{n}_{read} = \frac{\overline{t}_{read}}{t_{\text{Frame}}} \times N\,, \tag{4}$$

where N is the number of RU per frame.

Similar to the presentation in Eq. (1), the parameter $\overline{n}_{\text{Packet}}$ is introduced and the capacity fraction of a single packet data connection can be calculated by

$$\overline{\lambda}_{\text{Packet}} = \frac{\overline{n}_{pc} \times \overline{N}_{pc}}{\overline{n}_{read} \times (\overline{N}_{pc} - 1)} \equiv \frac{\overline{n}_{\text{Packet}}}{N}\,, \tag{5}$$

The parameters for web browsing (WWW) packet data services are summarized in Tab. 2 also including a *File Transfer Protocol* (FTP) single request model [13].

Table 2: Parameters for traffic models

Parameter	Speech	WWW	FTP
t_{Frame} [ms]	10	10	10
N [RU/Frame]	240	240	240
$\overline{N}_{pc}$	-	5	1
$\overline{t}_{read}$	-	12	-
t_D [s]	120	48	0.64
$\overline{S}_{pc}$ [kbit]	-	96	256
S_{RU} [bit] (SF 16)	-	232	232
$\overline{n}_{pc}$ [RU]	-	414	1110
n [RU/Frame]	2	0.43	variable
λ	0.0083	0.0018	n/N
DL:UL asymmetry	1:1	1:0	1:0 or 0:1

IV. RESULTS

Simulation results are obtained using both scenarios and different traffic mixtures of speech and packet data. Some important aspects to understand RRM mechanisms in CDMA UTRAN are presented in the following.

Power Control With the application of an SIR-based PC with a target level of -10 dB for speech service, interference is drastically reduced (see Fig. 6). Simulations with a traffic of 50 and 70 speech users per radio cell (Erlang) in the large Manhattan scenario are performed. In UL direction, a negligible contribution of inter-cell interference is obtained since all MS are received far below the background noise level. Without PC a interference floor of about -55 dB is visible. On the other hand SIR values are also reduced as illustrated in Fig. 7. Nevertheless, connection quality with BER$<10^{-3}$ can still be guaranteed (all users have experienced satisfactory QoS).

PC behavior is different in DL since joint detection at the mobile receivers restricts the dynamic range of the transmission powers for all connections within one timeslot to 20 dB. For DL transmission further improvement can be achieved by intelligent RRM strategies.

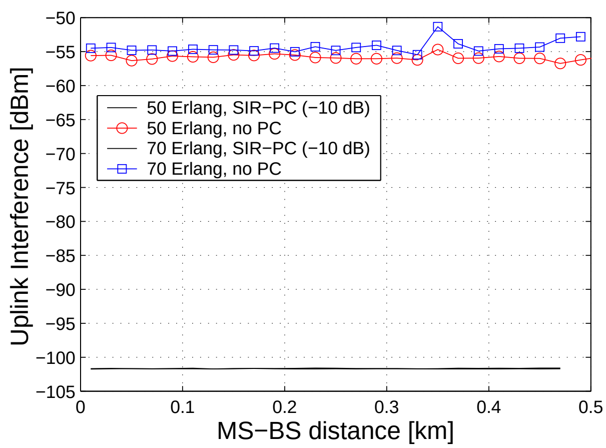

Figure 6: Reduction of interference with PC in UL

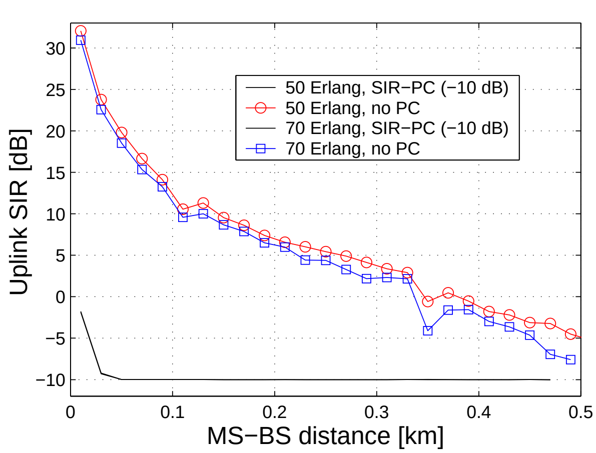

Figure 7: Degradation of SIR values in UL due to PC

Channel Allocation The LIR interference-based channel allocation is simulated and the achieved decrease of DL interference is presented in Fig. 8. Remaining is the interference at intersections at a distance of 115 m and 330 m from the BS. The LIR channel allocation algorithm outperforms FCA especially at low traffic, but also for very high traffic of 90 Erlang an advantage of LIR can be seen.

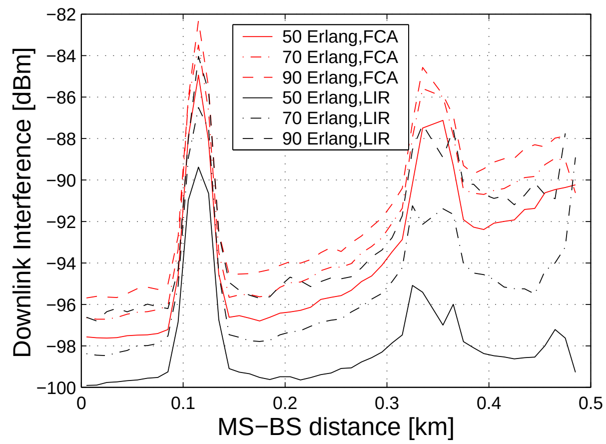

Figure 8: Performance evaluation of LIR allocation with respect to interference in DL transmission

Asymmetric TDD Frame Configuration In the presence of a service mix of circuit switched speech and packet switched web browsing traffic, an adaptation of the frame configuration to the offered traffic asymmetry is advantageous. Fig. 9 illustrates the *Satisfied User Criterion* (SUC) [10] versus the offered traffic in percent of the overall capacity. A nearly symmetric TDD frame with 8 DL and 7 UL slots or an asymmetric frame with 10 timeslots in DL is configured. SIR-based PC with targets -10 dB for speech and -7 dB for packet, and LIR channel allocation is applied within these simulations. Simulation environment is the small Manhattan scenario.

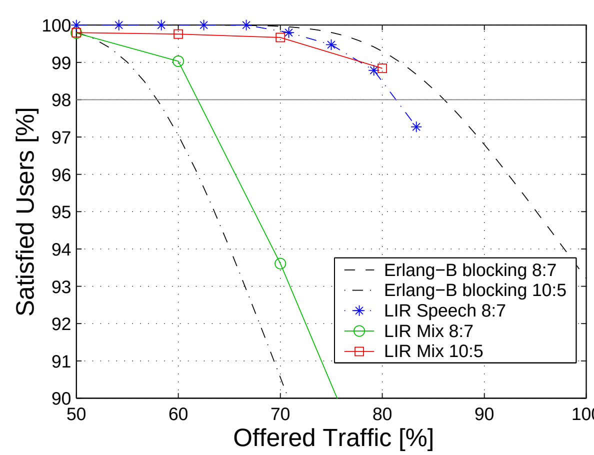

Figure 9: Satisfied user statistics for traffic mixture with ⅔ speech and ⅓ packet data traffic with symmetric and asymmetric TDD frame configuration

The degradation of the SUC is mainly caused by blocked connections or failed trials to reconnect to a BS after a reading period. The analytically derived Erlang blocking probability for restrictions due to 7 UL timeslots (112 RU) and 5 UL timeslots (80 RU) is plotted additionally. Speech service SUC evaluation is in line with the analytical results. Traffic mixture with ⅔ speech and ⅓ packet data in DL is obviously managed superior with a matched TDD frame configuration. Approximately the same system capacity as for speech only is achieved with the 10:5 DL:UL setting.

Throughput of Packet Data According to the SUC, a packet data user is satisfied if he gets at least 10 % of the required throughput as an active session throughput [10]. For the *Unconstrained Delay Data* (UDD) service with 384 kbps, an active session throughput of 38.4 kbps means satisfactory QoS.

The probability density function of throughput in DL presented in Fig. 10 is obtained with a scheduler parameterization to guarantee 46 kbps throughput so that all users admitted to the network have sufficient SUC. Overall offered traffic with ⅔ speech and ⅓ packet data is varied from 50 % to 80 %. Lower throughput values result only from not completely filled RU (remaining packet size is less than 29 byte). On the other hand, some packet connections have been refused by the network or aborted as no RU were available after the idle reading period.

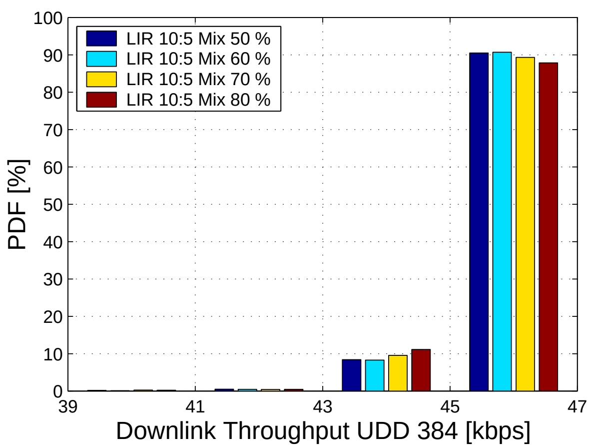

Figure 10: Throughput of data services at different offered traffics for asymmetric TDD frame configuration

V. CONCLUSION

Radio resource management issues for UMTS are discussed and simulation results about managing circuit and packet switched traffic on the CDMA air interface are presented. The TDD mode offers flexibility for adaptation to various traffic mixtures and intelligent algorithms for dynamically allocating resources can be applied.

With the application of optimized power control and joint detection, call admission control seems unnecessary in TDD mode and the available capacity will be the physical limit. Dynamic channel allocation can improve interference behavior. Remaining is the need for intelligent packet scheduling algorithms to be applied. An algorithm based on current transmission quality parameters is proposed.

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