Dynamic Channel Allocation in UMTS Terrestrial Radio Access TDD Systems

Ingo Forkel[1], Tham Kriengchaiyapruk[1], Bernhard Wegmann[2], Egon Schulz[2]
[1]Communication Networks, RWTH Aachen, Kopernikusstr. 16, D-52074 Aachen
[2]Siemens AG, Hofmannstr. 51, D-81359 München
Email: ingo.forkel@comnets.rwth-aachen.de

Abstract

The TDD operation mode of UMTS allows highly dynamic and various configurations of the physical layer time frame. A key issue in developing access methodologies to the available spectrum is an optimal management of the rare radio resources. In this paper, the application of interference based dynamic resource allocation is evaluated and compared to fixed channel allocation. The allocation dynamic bases on an attempt to offer connections instantaneous quality of service. Moreover, it allows rearrangement of the allocated resources in order to increase connection quality in case of a possible impending connection breakdown. As a decentralised algorithm, dynamic channel allocation offers among its performance gain the ease of implementation while reducing network planning.

1. Introduction

It is known from the existing mobile radio network systems that *Dynamic Channel Allocation* (DCA) allows the systems to utilize bandwidth more efficiently than the traditional *Fixed Channel Allocation* (FCA) scheme, and it also reduces network planning [1,2]. Besides some exceptions, e.g. IS-95, combinations of *Time Division Multiple Access* (TDMA) and *Frequency Division Multiple Access* (FDMA) are used in existing systems. The 3rd generation network UMTS implements an air interface, which introduces a *Code Division Multiple Access* (CDMA) component. This scheme is differently affected by the system's interference characteristics since all users share the same frequency band simultaneously [3].

Hence, multiple access interference due to restricted orthogonality of the used codes is the capacity limiting component in *UMTS Terrestrial Radio Access* (UTRA). In *Time Division Duplex* (TDD) mode, joint detection for the codes used within each single cell will be applied so that intra-cell interference can be neglected [4]. Remaining is the contingent of inter-cell interference originated by neighbouring cells, since non-orthogonal pseudo-noise scrambling sequences are used to distinguish different cells [5]. This interference situation demands for improved and flexible algorithms for an optimal radio resource management.

Moreover, while existing systems were designed mainly for speech, UMTS is also intended to support wireless multimedia communications (video, internet, etc.). The nature of data and internet traffic, however, is different from speech in terms of its appearance in short bursts with high peak data rates and long idle times between consecutive requests. For a combined voice and data transmission, *Quality of Service* (QoS) requirements with respect to transmission errors, throughput and delay must be considered. In addition, a different underlying physical layer and hardware-related restrictions and requirements must be considered.

In this paper, a comparison between channel allocation schemes with and without regard to QoS is drawn by means of system level simulations. The remainder of this paper is organised as follows. In Sec. 2 the TDD physical layer characteristic and the simulated channel allocation strategies are described. The simulation scenario and some relevant radio parameters are introduced in Sec. 3 whereas Sec. 4 contains the simulation results. Finally, Sec. 5 concludes the paper.

2. Channel Allocation

Physical Channel in UTRA-TDD

The considered UTRA physical channel consists of TDD frames of 10 ms in length, each divided into 15 timeslots [5]. Timeslots can either be used for *Downlink* (DL) or *Uplink* (UL) transmission divided by one (or even multiple) *Switching Point* (SP). Therefore, an asymmetric allocation of capacity is possible, contrary to a *Frequency Division Duplex* (FDD) mode in which paired frequency bands of symmetric width are assigned to DL and UL, respectively. In one timeslot a simultaneous transmission of up to 16 bursts by means of different spreading codes is possible. The combination of one code in one timeslot at a single operator's frequency band is referred to as *Resource Unit* (RU). Fig. 1 shows the structure of the physical channel within one TDD time frame. Moreover, it illustrates the ability of multi RU allocation by means of code pooling within one timeslot or multi-slot allocation in order to achieve higher data rates.

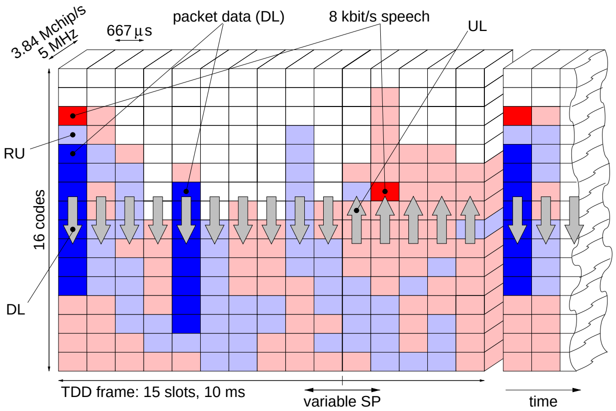

Fig. 1: Physical channel structure in TDD

In addition, UMTS holds the ability to assign different physical channel configurations, so-called transport formats, to a connection to allow for various transmission bit rates with different spreading factors and error correction schemes for several types of services. Nevertheless, with the help of code pooling these demands can also be considered. Hence, a fixed spreading of factor 16 is assumed to be applied in UTRA-TDD. In Fig. 2 the burst type 1 fitting into one RU as specified in [4] is presented. The two data fields contain 1952 complex valued chips since QPSK modulation is applied. With a spreading factor of 16 a total of 244 bit fit into one burst.

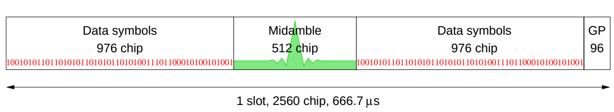

Fig. 2: Burst type 1 for TDD transmission

Speech data is fitted into one or more bursts depending on the *Adaptive Multi Rate* (AMR) code mode. Tab. 1 holds the physical channel configurations for two different AMR bit rates. The 8 kbps service with 50 % voice activity is considered in the following.

Tab. 1: Speech service requirements in UMTS

Service type (AMR coder mode)	Bit rate [kbps]	Avg. no. codes [DL/UL]
Speech 8 kbps	7.95	1/1
Speech 12 kbps	12.20	2/2

Fixed Channel Allocation

The FCA scheme allocates voice channel resources (one RU in DL and one in UL) within the frame randomly and assigns them, fixed, to the connection. In a scenario where only one specific type of voice communications is present, interference is expected to be spread uniformly over the entire frame and a similar quality of all timeslots can be assumed. A new call gets blocked if no free resource within the available RUs of the TDD frame can be found.

Although it can be assumed that interference is spread uniformly among all timeslots and therefore all user's connections experience a similar transmission quality, FCA suffers from the lack of intelligence to evaluate and adapt to the current link quality.

Dynamic Channel Allocation

Based on channel measurements, DCA schemes try to assign RUs to the connection which seem to offer the best available transmission quality while meeting the algorithm's constraints. A simple interference-based DCA methods operating decentralised at each single *Base Station* (BS) is introduced for speech service. It always assigns the *Least Interfered Resource* (LIR) in DL and UL to the connection (as evaluated for macro-cell scenarios in [6]). In addition, it allows to set interference thresholds for both link directions ($I_{Th,DL}$, $I_{Th,UL}$) to decide whether a timeslot provides an adequate quality or is unusable otherwise. Depending on the threshold settings, the number of rejected (blocked) and failed connections can be influenced since blocking probability increases as the interference threshold decreases. Further approaches follow a timeslot scoring depending on current load and quality situation [7].

Moreover, the proposed DCA offers the possibility to reallocate resources depending on the current connection quality as an additional feature. For speech services, this quality criteria can be the *Bit Error Ratio* (BER) of the connection. If, for example, the BER is higher than a pre-defined value for a certain period of time and the connection is going to fail, a reallocation request can be generated and executed in DCA and possibly better resources can be searched. Fig. 3 illustrates a BER-based reallocation after a timer t_{realloc} expires when the BER stays continuously above a given threshold. In case of a successful reallocation the connection can be prevented from being dropped after t_{dropp} (e.g. 5 s [8]). To avoid system instabilities reallocations are only permitted after a certain period of steady RU allocation. This is to consider possible failed reallocation attempts when the BER stays above the threshold also with the new resources and limits the dynamic of reallocation.

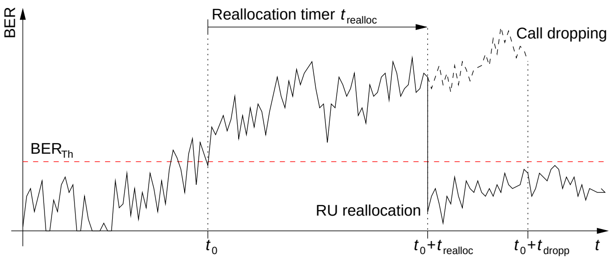

Fig. 3: BER-based dynamic reallocation of RU

3. Simulation Environment

Simulations have been carried out in two different Manhattan grid urban scenario based on the proposal given in [8]. In order to decrease the computational effort the number of BS in our scenarios has been reduced to 60 and 12, respectively (see Fig. 4). In the larger scenario only the inner six BS are evaluated.

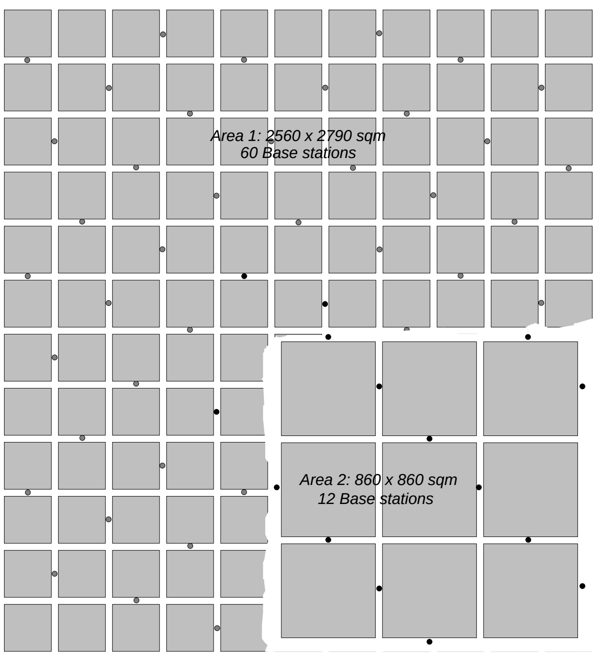

Fig. 4: Manhattan like urban scenarios

The results are evaluated with respect to the *Carrier to Interference Ratio* (CIR) and the *Satisfied User Criteria* (SUC) which contains the following parameters. For speech service a user is assumed to be satisfied if

- user does not get blocked by the system,
- BER does not exceed 10^{-3} (according to a CIR above –11.5 dB) for more than 5 % of the call duration,
- BER does not exceed 10^{-3} for longer than 5 s (call dropping criteria),
- call does not get dropped due to handover failure.

System capacity is estimated at 98 % satisfied users.

The considered frequency band is 1.900-1.905 GHz resulting in a background noise level of –102 dBm. The CIR-based power control target is set to –10 dB with DL dynamic range limitation set to 20 dB to allow for joint detection at the *User Equipment* (UE) [9]. Maximum carrier-sense handover algorithm with margin of 3 dB is applied. The TDD frame contains 8 DL and 7 UL timeslots.

The speech traffic model considers speech connections of an average duration of 120 s with 50 % activity in DL and UL direction where the active and silence times are negative exponential distributed with mean 3 s [8]. Offered traffic is varied by different inter arrival times of speech calls to the system.

4. Results

Comparing FCA to the LIR strategy in the 60 BS Manhattan scenario, it can be stated that interference is significantly reduced as illustrated in Fig. 5. Even for a traffic of 80 Erlang per cell the LIR algorithm yields lower interference floor than the FCA at 50 Erlang. Obvious is the unpropitious heavily interfered situation at the location of intersections in the scenario in distance 115 m and 345 m distance from the BS.

Like interference, CIR values are significantly improved. Fig. 6 illustrates the CIR distributions for these two allocation strategies at different traffic conditions. The curves for DCA are generally shifted to the left of the respective FCA curves which means better QoS in terms of BER for the connections. Concerning the 10^{th} percentile of the CIR distribution, the advantage of DCA becomes even more obvious as presented in Fig. 7, keeping in mind that for 10 % of the transmitted RUs in DL a CIR value below the presented value is experienced.

Similar results have been obtained in the 12 BS small Manhattan scenario. Less inter-cell interference is emitted in this environment (see Fig. 8) and only at one intersection in 215 m distance from the BS higher interference is present. From Fig. 9 and Fig. 10 a performance gain of DCA with reallocation over LIR can be obtained for high traffic (90 Erlang) only.

The SUC is only influenced by call blocking as illustrated in Fig. 11. The analytical Erlang-B blocking probability for 112 channels (as available in UL) is presented in addition. No dropped or unsatisfied calls due to high BER appear in the simulations.

In Fig. 12 is presented how FCA selects a timeslot randomly which results in a uniform allocation at all BS. LIR considers interference originated by other cells and neighbouring BS like the presented BS 30 and BS 31 located in the same street have a contrary allocation. Results are obtained at 70 Erlang traffic

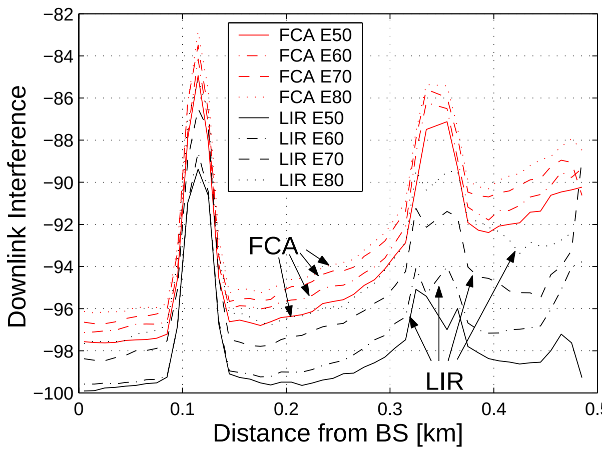

Fig. 5: Interference in DL versus distance in the large Manhattan scenario M_{60} with 60 BS

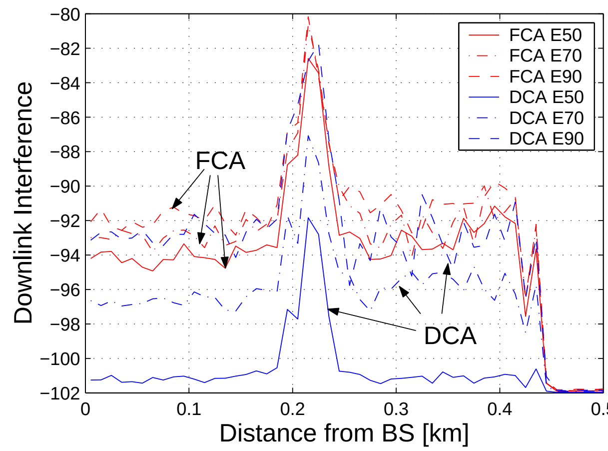

Fig. 8: Interference in DL versus distance in the small Manhattan scenario M_{12} with 12 BS

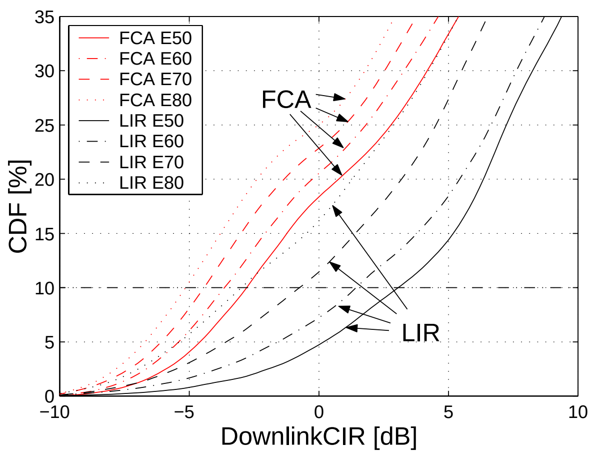

Fig. 6: Distribution of CIR values in DL (M_{60})

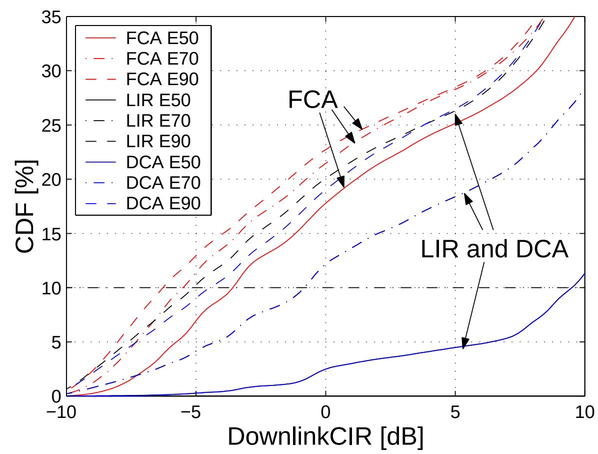

Fig. 9: Distribution of CIR values in DL (M_{12})

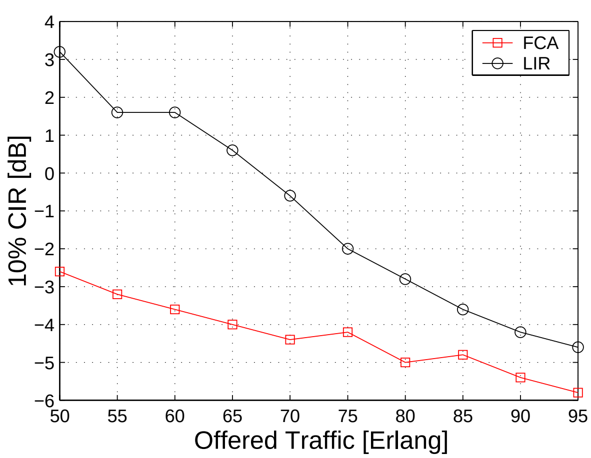

Fig. 7: 10^{th} percentile of DL CIR (M_{60})

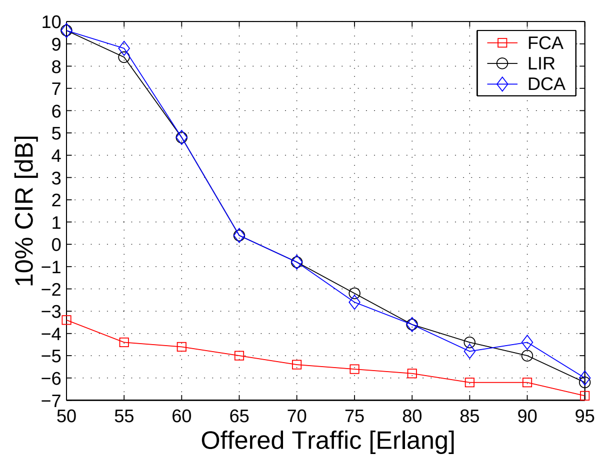

Fig. 10: 10^{th} percentile of DL CIR (M_{12})

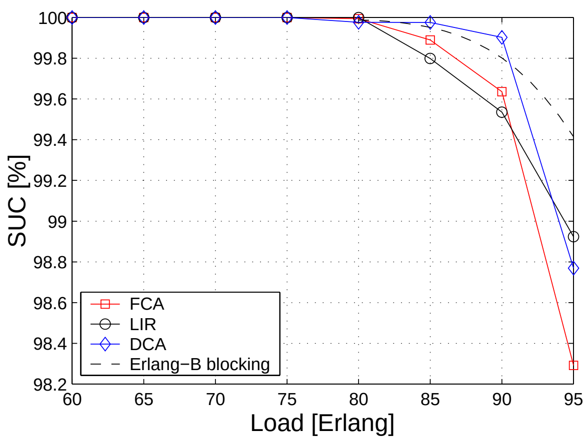

Fig. 11: SUC for FCA and DCA algorithm caused by call blocking (analytically derived Erlang-B equation for 112 available RUs in UL direction)

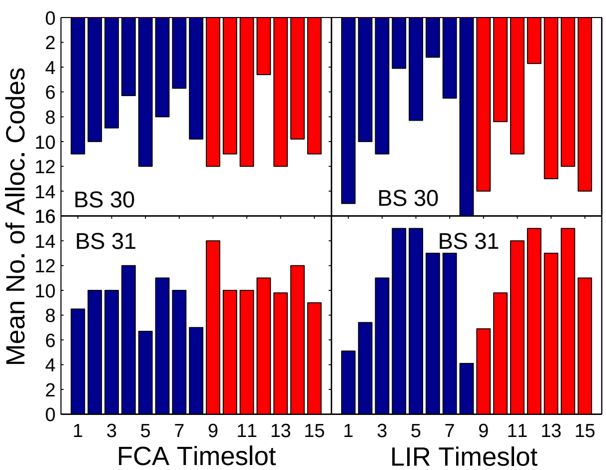

Fig. 12: Allocated RU at neighbouring BS for FCA and LIR channel allocation in scenario M_{60} at 70 Erlang

5. Conclusion

Simulation results of dynamic and fixed channel allocation for UTRA-TDD in urban scenarios are presented, showing the performance of FCA and DCA for UMTS speech service. The interference-based DCA has advantage over FCA in terms of CIR and BER performance. Furthermore, with the ability to reallocate resources with low transmission quality it offers improved QoS with respect to satisfied voice users.

Differences in the results of two simulation environments are presented. In order to analyse the performance of channel allocation algorithms even a small scenario offers appropriate traffic and interference situation. If optimal parameters for the algorithms have to be obtained, an increased simulation scenario with realistic interference characteristic becomes necessary.

Furthermore, simulation results show significant capacity in UTRA-TDD for a combined application of interference-based channel allocation and the CIR-based power control.

Further analysis should reveal DCA algorithms to adapt to traffic mixtures of speech and multimedia packet services with their different quality requirements. Scheduling issues and access to shared radio resources are for further study.

Acknowledgement

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