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DYNAMIC ALLOCATION OF CAPACITY IN UTRA-TDD SYSTEMS

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DYNAMIC ALLOCATION OF CAPACITY IN UTRA TDD SYSTEMS

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Abstract – This paper presents a *Dynamic Channel Allocation* (DCA) algorithm based on *Time Slot Scoring* method. The algorithm is designed for multimedia traffic in system which implements Time Division Code Division Multiple Access system (TD/CDMA). The algorithm tries to provide each service class appropriate *Quality of Service* (QoS). Simulations of a system using both *Fixed Channel Allocation* (FCA) and DCA have been carried out in both speech-only and mixed services environment to investigate the benefits of DCA.

Introduction

It is known from the existing mobile radio network systems that DCA allows the systems to utilise bandwidth more efficiently than traditional FCA schemes, and it also reduces network planning. But previously investigated DCAs in Katzela and Naghshineh (1) and in Ortigoza-Guerrero and Aghvami (2) so far did not address the issue of QoS of multiple services. The nature of data traffic is different from speech in terms of burstiness, peak rate, etc. In addition, the traffic in *uplink* (UL) and *downlink* (DL) are usually asymmetric. This paper presents a heuristic DCA algorithm designed to improve QoS of multimedia traffic in TD/CDMA mode. One such system is UMTS Terrestrial Radio Access in TDD mode (UTRA-TDD). Since UMTS is widely discussed and is being implemented, we pick UMTS 30.03 (3) as our guideline for simulations.

According to the specifications (4), the physical channel bandwidth is 5 MHz and lies between the frequency range of 2000 MHz and 2005 MHz. In the time domain, the bandwidth is divided into frames. The frame duration is 10 ms. Each frame is divided into 15 timeslots, each can be assigned as UL or DL transmission (but at least within a frame one slot has to be DL and one slot has to be UL). In each slot a simultaneous transmission of up to 16 bursts by means of different code sequences is possible. Each *Resource Unit* (RU) is specified by code and timeslot. In this configuration, 240 RUs are available per *Base Station* (BS) on a single frequency. The frame structure of UTRA-TDD is presented in **Figure 1**. Though many time configurations are possible, in this paper timeslots for DL is assumed to occupy the first part of the frame and UL slots occupy the second part.

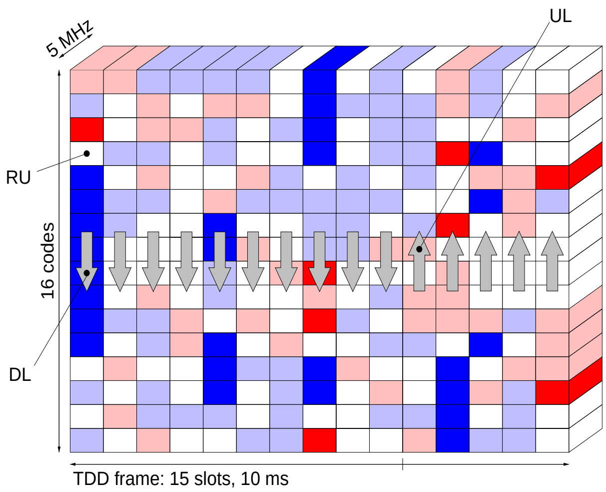

FIGURE 1 - TDD radio frame configuration

In multimedia traffic environment, it is likely that the traffic is not symmetric and there is more DL traffic due to the fact that most users will be downloading data. To take advantage of this characteristic, we can adjust the bandwidth to suit the traffic ratio by assigning different number of timeslots as UL and DL. Also, each service may require different throughput. Allocation algorithm should be able to assign different number of RUs to satisfy the throughput demand. In addition, each service has different throughput and *Bit Error Ratio* (BER) requirement. Allocation algorithm can accommodate this by considering the interference requirement. Two different timeslots, which have the same number of available RUs, may suit one service type but may not be appropriate for another, due to different interference situation. Another factor is the interference characteristic in CDMA systems. CDMA provides graceful degradation of interference situation within one timeslot. This means as more users are added to a timeslot, the interference situation in that slot gradually deteriorates. Existing users in that timeslot, who may not experience severe interference before, can receive additional interference created by the new users.

Channel Allocation Algorithms

This paper investigates performance of DCA. As the basis for comparison, we chose a simple FCA algorithm. FCA allocates channel resources within the frame randomly and assigns them fixed to the connection. After randomisation, if the chosen slot is full, the subsequent slots are searched until a free slot is found. If all slots are occupied, the call will be blocked. Speech service requires one RU in UL and one RU in DL. Therefore FCA searches for one free RU in each direction. However, packet service usually requires more than one RU. In this case, FCA can perform allocation if and only if it finds a timeslot with free RUs as requested by the service. If both UL and DL allocations must be done, FCA must be able to find enough RUs in both direction. Otherwise, the call will be blocked or disconnected. The number of UL and DL timeslots cannot be changed by FCA.

DCA ensures QoS for each call by assigning each call appropriate number of resources that have adequate interference situation. Like FCA, the numbers of UL and DL slots also remain fixed. There is no shifting of switching point between UL and DL transmission. DCA is based on *Time Slot Scoring Algorithm* which can be described in steps as follows:

1. Each service type (speech, packet) has its own set of UL and DL interference limits (I_{max-UL} and I_{max-DL}). This interference limits suggest the border line where the data (or voice) can be transmitted and received appropriately. Also, the optimal number of RUs required per frame per UL and DL must be parameterised for each service. This parameter allows system operator to provide different packet data service classes, based on transmission speed. Because more RUs per frame usually leads to higher throughput, but also higher blocking probability.
2. At the time of initiation of a connection, the call measures signal quality from local base stations and sends a connection request to the station with the best signal quality. Then DCA obtains interference data for each time slot. In UL, the interference is measured at the base station position, while for DL the interference is measured at the position of the mobile.
3. DCA considers the interference data. Any slot with interference level lower than the predefined threshold and has free RU, +4 points are given. Otherwise, -1 score will be assigned and that timeslot will be dropped from further consideration.
4. DCA now considers the number of unallocated RUs within the frame and the number of RUs required by the call's service type. If a slot has enough RUs required by the service, another +4 points are given.
5. If the slot has RUs for only 50% of the required capacity, +2 extra points are given.
6. Otherwise, if the slot can support a connection with at least 1 RU, only +1 point is given.
7. Finally, the slot with the highest score is chosen. If more than one slot have highest score, any of them can be chosen. In our algorithm selects the one that is found first. If both UL and DL allocations must be done, DCA must be able to find RUs in both direction. Otherwise, call will be dropped.

In step 3, DCA tries to ensure that each slot has adequate level of interference to support each service class, while the scoring in step 4 to step 6 is done to ensure that each call has sufficient RUs as required by the service.

An example of how the algorithm runs is provided here. Suppose a packet service call needs 8 RUs in DL and 1 RU in UL. The scoring scheme according to the frame in **Figure 2** proceeds as in **Table 1**.

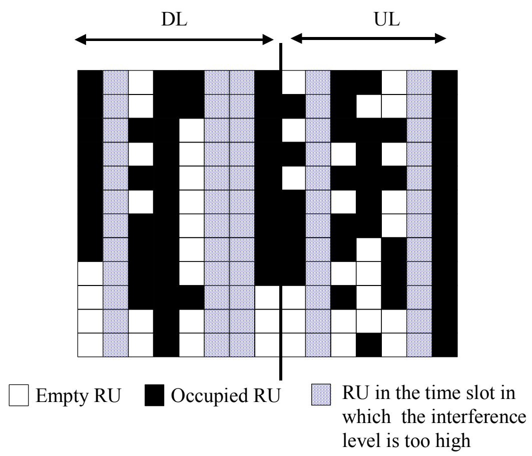

FIGURE 2 - Current status of a time frame

Assuming step one and two of the algorithm are performed. In step three, slot 1, 3, 5, 6, 9, 13, 14 are discarded either because the interference level is too high for this type of call, or no RU is available. During step four to six, either +4, +2, and +1 points are added

TABLE 1 - Example of Timeslot Scoring Algorithm

Slot / Step	DL Timeslots								UL Timeslots						
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Step 3	4	-1	4	-1	4	-1	-1	4	4	-1	4	4	4	-1	-1
Step 4-6	2	-	2	-	4	-	-	1	4	-	4	4	4	-	-
Sum	6	-1	6	-1	8	-1	-1	5	8	-1	8	8	8	-1	-1

to scores of the remaining usable slots, depending on the number of RUs available in each slot. In the end, slot four has the highest score and is chosen for DL and eight RUs are given to the call. In UL direction, there are many slots with the highest score. Slot eight is chosen by the algorithm as the first available.

Simulation

The simulations have been carried out, using (3) as our guideline with some exceptions. In contrast to the recommended 72-base-station Manhattan scenario, our smaller Manhattan scenario consists of 12 BSs as depicted in **Figure 3**. The differences between two scenarios can be found in **Table 2**.

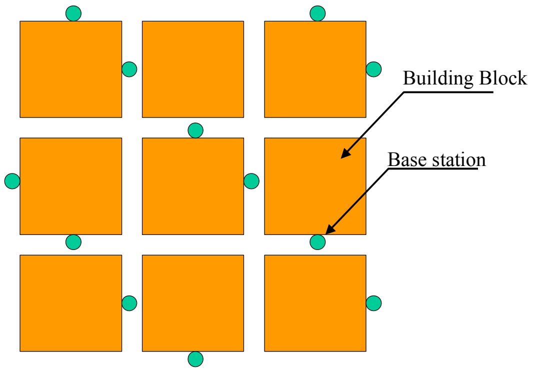

FIGURE 3 - Small Manhattan Scenario

TABLE 2 - Differences between small Manhattan and UMTS 30.03 Manhattan

	Small Manhattan	UMTS30.03 Manhattan
Number of BSs	12	72
Distance between neighbouring BSs	860 m	920 m
Number of road intersections between 2 BSs	2	4
Building Block Size	400 m x 400 m	200 m x 200 m
Total Area	1.74 km^2	6.5 km^2

Since we only want to compare two allocation algorithms, rather than finding the capacity border of the system, 12-station scenario helps reduce complexity of computation. To preserve the interference characteristic, the distance between two neighbouring stations in the smaller scenario is kept close to that in the original scenario (860 m versus 920 m). This is done by enlarging the original building block size from 200 mx200 m to 400 m x 400 m. The street width is kept fixed at 30 m. Because of the building block enlargement, we have fewer road crossings between BSs. The shadowing in the smaller scenario is the same as in the big scenario, which is log-normal shadowing with 10 dB standard deviation and zero mean.

In terms of services, we have two models: speech and packet. Speech call service is modelled as a two-state model with the parameters shown in **Table 3**. As evaluation criteria in (3) specifies *satisfied user criteria* (SUC) for speech call which can be summarised as follows:

1. Call is not blocked or disconnected during hand-over.
2. Connection has sufficiently good quality (*BER* $< 10^{-3}$), more than 95% of the connection period.
3. User is not disconnected. Disconnection occurs when *BER* $> 10^{-3}$ more than 5 seconds.

TABLE 3 - Speech Service Parameters

Parameter	Value
Call Duration	Mean 120 s, exponentially distributed
Active/Silent Period	3 s
Activity	50%
RU requirement	1 RU in DL and 1 RU in UL

Since we want to simulate algorithm when UL and DL traffics are asymmetric, our packet service is modelled as DL only. The arrival process of sessions is also Poisson. When a call arrives, it is either given a channel or blocked. Packet service consists of two phases: *reading* and *download*. During the reading phase, user stays in the system but remains inactive. When the reading period is over, mobile becomes active and goes into download phase. At the beginning of download phase, a random amount of data is generated and mobile tries to reconnect to the system by requesting a channel. Once given, the channel stays fixed and is exclusive for that call until all the data has been downloaded, or until a hand-over must be performed. If allocation algorithm cannot find a channel when a call reconnects, the call is disconnected (no queuing). Within a frame, all data in allocated RUs is either sent correctly, or not at all. When assigned with four RUs per frame in DL, this call type has a maximum theoretical throughput of 80 kbps, assuming each RU carries roughly 25 bytes per frame (5). After all data is sent, the call releases the channel and goes into the reading period. A packet call is considered satisfied, if it meets the following SUC:

1. User is not blocked or dropped.
2. Finished with active session throughput above 6.4 kbps.

TABLE 4 - Packet Service Parameters

Parameter	Value
Avg. number of downloads	5
Avg. size of a download	12000 bytes
Avg. reading time	12 s
Optimal RU requirement	4 RUs in DL

Mobility model is as documented in (3). Joint Detection is applied. Power control algorithm is disabled. Margin-based (3 dB margin) hand-over is performed.

Results

First, we evaluate DCA when there are only speech calls in the system. The result is shown in **Figure 4**.

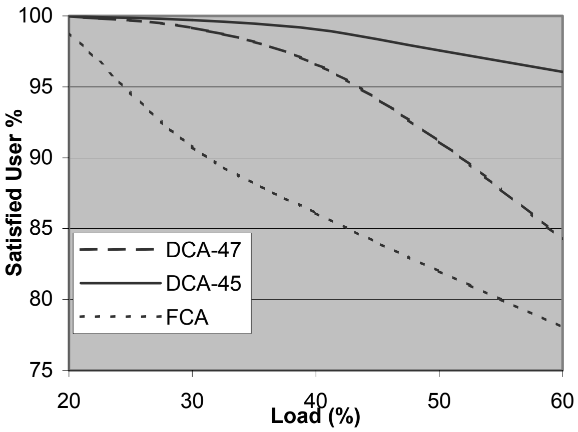

FIGURE 4 - SUP Evaluation (speech-only)

X-axis shows the average system load per base station in percent. At 100% load, all of 240 RUs in every frame are completely used up. Y-axis represents the satisfied user percentage, evaluated according to the SUC presented in the previous section. In this scenario, the traffic is symmetric because a speech call requires one RU in DL and one RU in UL. DCA-47 line shows the satisfied user percentage at various loads, when $I_{max\text{-}UL}$ is –47 dB and $I_{max\text{-}DL}$ is –41 dB. Similarly, DCA-45 sets $I_{max\text{-}UL}$ at –45 dB and $I_{max\text{-}DL}$ at –39 dB. FCA line is the result from FCA algorithm. By adjusting interference limits, we can effect the performance of DCA. If the interference limit is too stringent (for example as in DCA-47), new calls will be often blocked and *Satisfied User Percentage* (SUP) decreases. But if the limits are too high, DCA will add more calls to the system than the system can handle. This can lead to degradation in signal quality and increment in call disconnection. In the end, SUP suffers as a result. With **Figure 4**, system operator can choose a point of operation (such as 98% SUP as recommended in (3)) and see the capacity gain from using DCA.

In mixed traffic environment, each BS is loaded equally with asymmetric traffic. About one-third of the traffic is in UL direction and consists of speech calls only. Another one-third of the traffic is in DL as speech calls. Another one-third of the traffic is also in DL, but as packet data. This means DL is loaded more heavily with two-third of the traffic. For example, when the system is loaded at 30%, 10% of the traffic is in UL as speech service, another 10% in DL as speech service, the rest 10% is also in DL, as packet service. **Figure 5** illustrates the SUC when we have almost-symmetric frame configuration (8 DL slots, 7 UL slots) while having asymmetric traffic load (2 DL : 1 UL). There are three separate lines for FCA and DCA. The solid line depicts the overall average SUP for packet and speech calls. The other two lines shows the SUP for speech mobiles and packet mobiles separately. **Figure 6** shows the bit rate distribution for packet calls at load 20% up to 50% (L20-L50).

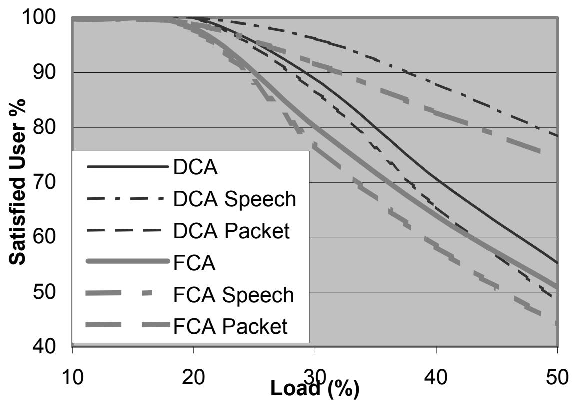

FIGURE 5 - SUP Evaluation (mixed traffic, 8 DL slots, 7 UL slots)

Shown in **Figure 5**, DCA can carry higher traffic load for the same SUP. This can be explained by **Figure 6**. For packet service, DCA has information about interference limit of packet service, it can provide higher throughput than FCA at the same traffic load by selecting timeslots with acceptable interference situation. Higher throughput allows packet calls to download data faster and finish sooner and there is less accumulated traffic. System operating with FCA on the other hand cannot deliver enough throughput and accumulates more and more load as new users arrive in the system. (Our simulation applies neither packet queuing nor admission control.) More users cause more interference, which again leads to even lower throughput.

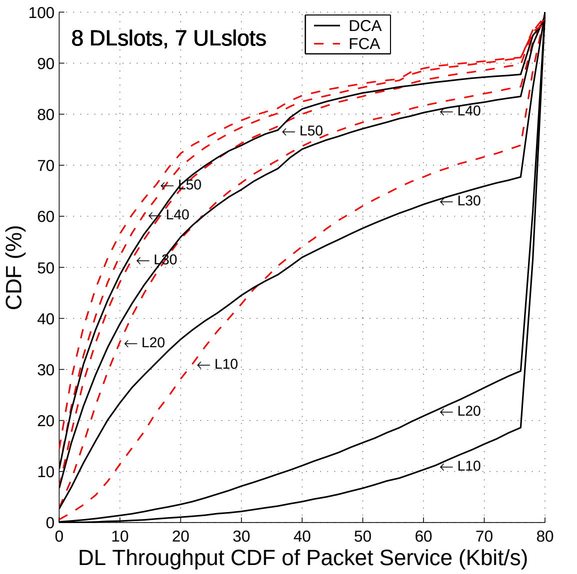

FIGURE 6 - CDF of throughput of packet calls (mixed traffic, 8 DL slots, 7 UL slots)

The capacity of the system can be improved further by adjusting the number of UL and DL timeslots to fit the traffic demand. In the second set of results in **Figure 7 and 8**, we adjust the frame configuration so that we have 10 DL slots and 5 UL slots, which is the same ratio as the traffic demand.

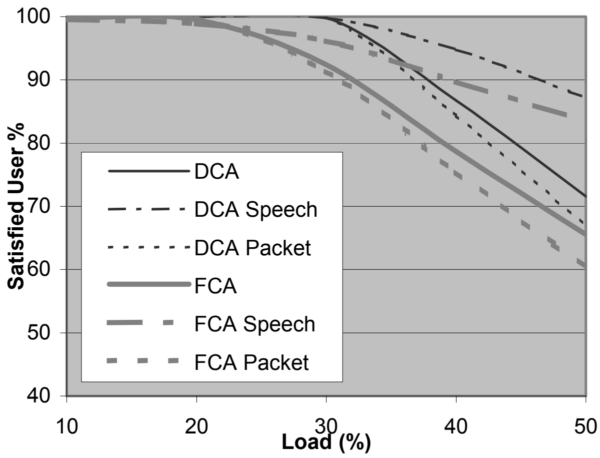

FIGURE 7 - SUP Evaluation (mixed traffic, 10 DL slots, 5 UL slots)

Conclusion

Authors presents a DCA designed for multiple service classes. To make a decision, DCA makes use of interference measurement, interference limits and RUs requirement parameters of each service. By adjusting the interference limit parameters, system operator can influence the number of blocked calls and radio link failures. RUs requirement parameters allow system operator to adjust the throughput of packet data service. Currently the numbers of UL and DL slots are fixed. In the future, DCA should be able to assign UL and DL slots dynamically based on the traffic demand. Finally, to ensure on-time delivery of real-time packet service, scheduling and queuing technique should be implemented.

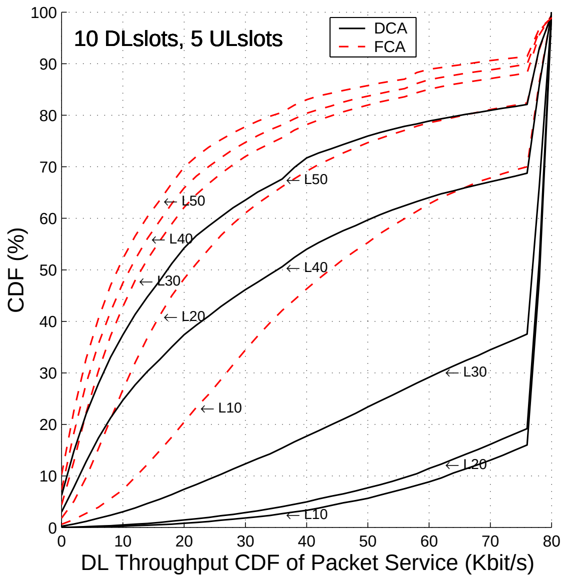

FIGURE 8 - CDF of throughput of packet calls (mixed traffic, 10 DL, slots, 5 UL slots)

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References

1. I. Katzela and M. Naghshineh,, June 1996, "Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: A Comprehensive Survey", IEEE Personal Communications, 10-31.
2. L. Ortigoza-Guerrero and A. Hamid Aghvami., 1999, "Resource Allocation in Hierarchical Cellular Systems.", Artech House Publishers, Boston.
3. ETSI. TR 101 112, Apr. 1998, "Selection Procedure for the Choice of Radio Transmission Technologies of the Universal Mobile Telecommunication System UMTS (UMTS 30.03)".
4. 3GPP, Oct. 1999, "TS 25.22x – Physical Layer, General Description (TDD). Technical report", 3rd Generation Partnership Project.
5. B. Walke., 1999, "Mobile Radio Networks". John Wiley & Sons, Chichester, UK.