8

Traffic based Dynamic Channel Allocation Schemes for WLL

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8.1 Introduction

The need for providing telecommunication services is growing faster than ever. For this purpose *Wireless Local Loop* (WLL) also known as *Fixed Wireless Access* (FWA) Networks is an effective alternative to the problematic wired system. Compared to mobile systems, FWA networks provide two-way communication services to near-stationary users within a small area [8].

The next section presents an overview of multiple access schemes. Channel allocation strategies are described in the second part of the section. The emphasis here is on fixed and dynamic channel allocation schemes. A unique *Dynamic Channel Allocation* (DCA) technique for a *Wireless Asynchronous Transfer Mode* (WATM) system based on the *Carrier to Interference ratio* (C/I) measuring is presented. This technique is explained in detail as it provides the concept for the simulator which is used for the analysis of the broadband FWA network.

The FWA network scenario and its parameters are presented in the following section. The parameters of the radio channel are explained as well as the traffic models and the system parameters such as its geometrical setting and radio characteristics.

Simulation results of *Time Division Multiple Access* (TDMA) with DCA are presented. The effects of different capacity enhancing schemes suitable in WLL scenarios for the proposed algorithm are investigated and evaluated.

8.2 Access and Allocation Technologies

Presented in this section is a description of multiple access technologies and an overview of existing channel allocation schemes. An extended version with some examples explained in more detail is given in [5].

8.2.1 Multiple Access Technology

A defined radio bandwidth can be divided into a set of defined radio channels. Each channel can be used simultaneously while maintaining an acceptable received radio signal.

The radio spectrum can be divided into separate channels using splitting techniques such as *Frequency Division* (FD), *Time Division* (TD) or *Code Division* (CD) multiple access. Let $S_i(k)$ be the set i of wireless terminals that communicate with each other using the same channel k. By taking advantage of the radio propagation loss, the same k channels can be reused by another set j if both, i and j are spaced sufficiently apart. All sets which use the same channel are known as co-channels. The co-channel re-use distance σ denotes the minimum distance for re-use of the channel with an acceptable level of interference. A channel can be reused by a number of co-channels if the C/I in each co-channel is above a required minimum C/I. C represents the received signal power in a channel and I is the sum of all received signal powers of all the co-channels.

Consider the scenario depicted in Figure 8.1.

Here, an *Radio Network Terminal* $(\mathrm{RNT})_t$ is transmitting to its *Radio Base Station* (RBS) located at a distance d_t. Five surrounding RNTs, communicating with their respective RBS located at distances $d_1 \ldots d_5$ on the same channel as RNT_t, cause interference at RBS_t.

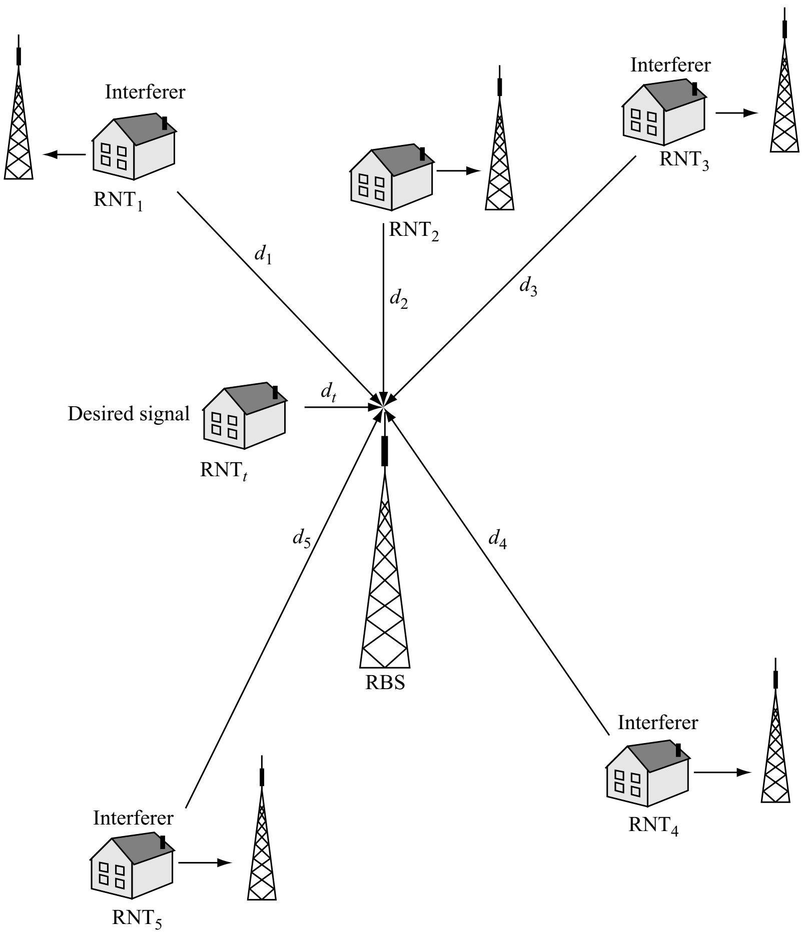


Figure 8.1 Co-channel interference

Denoting the transmission power of the RNTs with $P_{i=t,1,\ldots,5}$ then Equation (8.1) describes the co-channel interference caused at the reference RBS in an abstract form. N here is the background noise and α is the propagation coefficient which is determined by the terrain

$$C/I = \frac{P_t d_t^{-\alpha}}{\sum_{i=1}^{5} P_i d_i^{-\alpha} + N} \tag{8.1}$$

As Equation (8.1) shows there are different methods of obtaining a satisfactory C/I at the reference station RBS. For example, the distance between the co-channel stations can be increased, or the interfering power can be reduced (or increasing of desired signal power P_t). The latter describes the motivation underlying the power control schemes.

8.2.2 Channel Allocation Technology

Channel allocation schemes can be divided into *Fixed Channel Allocation* (FCA), *Dynamic Channel Allocation* (DCA) and *Hybrid Channel Allocation* (HCA). These allocation schemes are based on the method in which the co-channels are separated.

8.2.2.1 Fixed Channel Allocation

In an FCA strategy neighbouring radio cells are grouped together to form clusters. The total number of available channels is divided into sets. Each radio cell in a cluster is allocated a set of these radio channels. The number of channels and with that the cluster size within the set is dependent on the frequency re-use distance and the required signal quality.

Considering a hexagonal cell with radius R and a distance D between the cluster centres, the minimum number n of channel sets necessary to cover the FWA network area is

$$n = \frac{1}{3}\sigma^2 \quad \text{whereby} \quad \sigma = \frac{D}{R} \tag{8.2}$$

For $\sigma = 3$, the minimum number of radio channel sets is $n = 3$. In the simple FCA strategy the same number of radio channels is allocated to each cell. This distribution is efficient for a uniform traffic load distribution in the FWA network system. In this case the blocking probability in one cell is the same as the blocking probability of the whole system. FCA strategies require careful planning of the distribution of channels and cells.

The implementation of FCA is simple since it is a static system. However, FCA reaches its limit when it has to serve a varying traffic load in the FWA network system.

FCA encounters a problem. If the traffic distribution within the radio system is uneven, it can happen that the blocking probability in heavily traffic loaded radio cells quickly reaches a maximum despite free channels which are present in lightly loaded radio cells. The resulting effect is a poor channel utilization. To improve this utilization either non-uniform channel allocation or channel borrowing schemes may be applied.

8.2.2.2 Dynamic Channel Allocation

As opposed to FCA, in DCA there is no exclusive association between channel and the radio cell. As a result, DCA strategies are able to react flexibly to local and temporal variations of mixed traffic and load distributions [5]. A radio channel is used by any radio cell as long as signal interference constraints are met. There are three major types of DCA strategies, centralized, decentralized, and C/I measurement based schemes.

In Table 8.1 an overview of the different strategies is presented. For FWA networks the schemes *Dynamic Channel Selection* (DCS), already in use within the *Digital Enhanced Cordless Telephone* (DECT) system, and *Channel Segregation* (CS) are believed to have the greatest importance. However, the schemes must be adapted for the FWA scenario.

8.2.3 Dynamic Channel Allocation for FWA Networks

The FWA network scenario must support a packet-oriented environment like ATM. Since ATM implies different *Quality of Service* (QoS) and bandwidth requirements, the implementation of DCA as a channel assignment strategy seems appropriate. As mentioned before DCA is able to react flexibly to fluctuations in traffic. For real-time services classes like *Variable Bit Rate* (VBR) there must always be enough capacity to guarantee transmission of the cells.

All channel allocation strategies are based on the assignment to physical channels. The various channel access protocols perform the characteristic statistical multiplexing of ATM cells of RNTs in the service area of an RBS. The channel access is co-ordinated by the RBS. The virtual connections of the RBS to the RNTs occupy the entire frequency spectrum.

The problem of the capacity allocation is to find a method to give each RBS sufficient capacity. An RBS should only be given that portion of the frequency which is really necessary, while the remaining part is delivered to the other RBSs. However, the allocation dynamic must be held minimal to avoid interference to the other RBSs.

Table 8.1 Overview of DCA schemes

Category	Scheme
Central DCA	First Available Locally Optimized Dynamic Assignment Selection with Maximum Reuse Ring Usage Mean Square Nearest Neightbour 1-Clique
Distributed DCA	Locally packing distributed DCA Moving Direction
C/I measurement based DCA	Sequential channel search Minimum Signal-to-Noise Interference Ratio Dynamic channel selection Channel segregation

The studied system has a carrier frequency of 28.5 GHz with a bit rate of up to 112 Mbit/s if *Quaternary Phase Shift Keying* (QPSK) modulation is considered. The available spectrum can be divided into channels, corresponding to the number of frequencies set for the spectrum. The cell radius of the FWA network lies in the range of up to 2500 m. The allocation of a complete frequency as a physical channel is uneconomical as the RBS does not require the complete resource all the time. Hence, the idea of splitting the total capacity within a frequency band into multiple resource units by time division multiplex seems appropriate.

DCA Principle Following is a method to implement a DCA scheme for WATM in for FWA. The problem which is characteristic of DCA is that the scheme requires a steady behaviour whereas ATM load is synonymous for dynamic behaviour. The technique presented here is based on a C/I measuring DCA scheme.

The Medium Access Protocol The *Medium Access Control* (MAC) protocol applied here is very much like the European HIPERLAN/2 system and a candidate for the HIPERACCESS standard. It controls the access of the RNTs and the RBSs to the shared radio channel. The access is co-ordinated by the RBS which acts as a central instance. The RBS allocates capacity to the RNTs on a slot by slot basis. The scheduler within the RBS does not have any direct information on the waiting buffers of the RNTs. Rather, the RBS contains a mirror of each RNTs occupancy state of the send buffer. This information is sent from the RNT to the RBS via a signalling scheme. The MAC protocol divides the transmission into signalling periods. The length of the signalling period can be variable, however, here it is of a fixed length. The signalling period of the transmission can be divided into four phases as depicted in Figure 8.2.

The four different transmission phases in each fixed length signalling period are explained in the following:

- *Broadcast phase*: This phase consists of the broadcast control channel which contains general information and is sent at the beginning of each frame. The phase also consists of a frame control channel which contains information on the next frame.
- *Downlink phase*: During the downlink phase control units and data units are sent from the RBS to the respective RNTs.

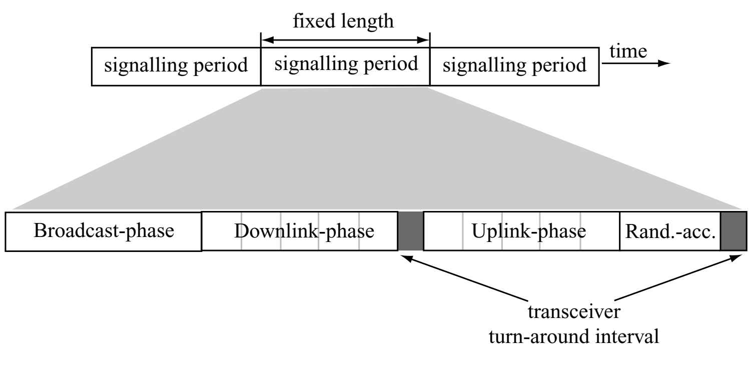


Figure 8.2 Structure of the MAC frame

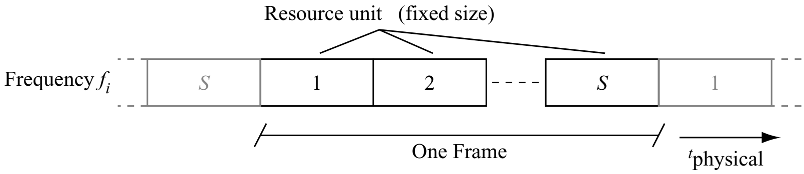


Figure 8.3 Frame structure of the physical channel

- *Uplink phase*: The uplink phase is similar to the downlink phase with the exception that the transmission is from the RNTs to the RBS.
- *Random access phase*: The RNTs send control information to the RBS in a contention based manner, which means that collisions can take place.

Method A frequency is divided into intervals of equal length using TDMA. A fixed number of intervals S (now called resource units) are grouped together to form a frame. In the course of the simulations the size of a resource unit was set to 5 slots (5 ATM cells), giving a duration of 100 μs.

The channel allocation for an RBS takes place during a resource unit (or several resource units) according to the capacity required by the RNTs' connections. A frame is repeated periodically, thereby creating a steady behaviour, since an RBS allocates the same resource unit in every frame. In effect, a new physical channel has been created. The allocation takes place on the basis of interference measurements. The measurements are done on many frames but always on the same resource unit for each RBS.

The MAC protocol is in charge of co-ordinating the access of the RBS and the RNTs to the channel within the allocated resource unit(s). As a result, within the resource units a dynamic capacity allocation takes place according to the need expressed by the RNT.

8.3 FWA Network Scenarios

This chapter contains a description of the FWA network scenario and its parameters. This is also the basis for the capacity analysis between simulative TDMA and analytical *Code Division Multiple Access* (CDMA) in Chapter [Ref Chapter CDMA vs TDMA].

8.3.1 Basic Parameters of the FWA Network Scenario

System Setup The FWA network simulations are carried out with a hexagonal cell scenario containing 61 cells. One RBS is placed in the centre of each cell and 48 RNTs are uniformly distributed over each single cell area. The inner 19 cells are evaluated and the outer two rings of cells produce additional interference to achieve a realistic traffic and frequency usage for the simulation.

Cell Sizes By means of experiments conducted in San Francisco and nearby areas it was determined that the optimal FWA network could have a cell size radius of approximately

2 km [12]. The simulations will be carried out using cells with this radius. Table 8.2 summarizes the basic system parameters.

8.3.2 Radio Aspects

Spectral Efficiency and Available Bit Rate According to German spectrum regulations [11], the available bandwidth per FWA-operator at 26 GHz will be 56 MHz. Assume the values in Table 8.3, in order to define the spectral efficiency of the particular modulation schemes with variable bit rates.

Using this basic spectrum efficiency model, the available bit rate, that is supported by the system is calculated to 112 Mbit/s for QPSK modulation, and if 16 *Quadrature Amplitude Modulation* (QAM) is used 224 Mbit/s [10].

If the frequency band is divided into sub-carriers, the available bandwidth in the sub-bands leads to a certain transmission speed. The TDMA simulations are carried out for four sub-bands within the entire bandwidth available for the DCA and FCA evaluations. Assuming the length of a MAC-*Packet Data Unit* (PDU) on the physical layer to be about 800 bit (including coding, and protocol overhead) a total of

$$\frac{112\ \text{Mbit/s}}{800\ \text{bit/cell} \times 4\ \text{frequencies}} = 35\,000\ \text{cells/s/frequency} \tag{8.3}$$

can be carried using QPSK modulation. The duration of a slot carrying one MAC-PDU with one ATM cell as payload is then 28.6 μs. The use of a higher-order modulation

Table 8.2 Simulation parameters

Parameter	Value
Cells	61 (inner 19 evaluated)
Cell radius [km]	2.0
RBSs per cell	1
Sectors per cell	1[1] or 6[2]
RNTs per sector	48[1] or 8[2]

[1] Omni-directional RBS antenna
[2] Sectorization at the RBS applied.

Table 8.3 Spectral Efficiencies

Modulation	Spectral Efficiency[1]	Available Bit Rate	Slot Duration
QPSK	2.0 (1.5) b/s/Hz	112 (84) Mbit/s	28.6 μs
16 QAM	4.0 (3.5) b/s/Hz	224 (196) Mbit/s	14.3 μs

[1] Basic example values proposed in (NORTEL NETWORKS, 1999) in brackets.

scheme results in higher transmission bit rates corresponding to smaller slot duration. Also in the case the modulation order is to be changed, the resource unit duration must be kept constant. The number of slots per resource unit would then be increased.

Propagation Model In the propagation model employed in the simulator a transmission coefficient n models the propagation in different environments like urban, sub-urban, residential, or hilly terrain. Based on measurements in German urban areas $n = 2.7$ has been selected [1].

The path loss model implemented in the simulator is described by

$$L_{\mathrm{PL}}(d) = L_F(d_0) + 10n\log(d/d_0) \tag{8.4}$$

where n is the propagation coefficient discussed before. The reference path loss value $L_F(d_0)$ in a distance $d_0 = 1\,\mathrm{m}$ is calculated based on the free space path loss formula

$$L_F(d) = 20\log\left[\frac{4\pi d}{\lambda}\right] - G_{\mathrm{Antennas}} \tag{8.5}$$

with wavelength and the gains of the transmitter and receiver antennas. Hence, the reference path loss is $L_0 = 61.55\,\mathrm{dB}$. This leads to a maximum path loss in distance $d = 2\,\mathrm{km}$ at the edge of coverage of $L_{\mathrm{PL,max}} = L_{\mathrm{PL}}(d = 2\,\mathrm{km}) = 150.67\,\mathrm{dB}$. The path loss of all stations to each other are based on this path loss model.

Additionally, a fading margin of 3 dB is included in the propagation model to acknowledge the fading effects caused by multipath propagation and signal shadowing.

Background Noise Considering a background noise power spectral density of $N_0 = 4\,\mathrm{pW/GHz}$ a noise level of $-97.5\,\mathrm{dBm}$ for the frequency band of 56 MHz is found. If the whole bandwidth is divided into four sub-bands, each frequency band is disturbed by a noise level of $-102.5\,\mathrm{dBm}$.

Additional noise is caused by the receiver components. A receiver noise figure of 5 dB is considered in the simulations, taking into account the high quality devices applicable at the FWA network subscriber radio units and the RBSs. Including the receiver noise figure a background noise level of $-97.5\,\mathrm{dBm}$ is finally adopted.

Root Mean Square Delay Spread Measurements carried out at the University of Paderborn for an FWA scenario at 29.5 GHz revealed that multipath at this carrier frequency practically does not exist [4]. This may be due to the very strong *Loss of Sight* (LoS) component between the RNT and RBS, or due to technical limitations in the measuring equipment. In fact an RMS delay spread of $\mathrm{DS} = 1\,\mathrm{ns}$ can hardly be measured.

Transmission Power The transmission powers of the RBS and the RNT depend on eventual antenna gains, the attenuation of the radio link between RBS and RNT and the background noise level. Considering the background noise level at $-97.5\,\mathrm{dBm}$, the maximum path loss of $L_{\mathrm{PL,max}} = 150.67\,\mathrm{dB}$, the assumed fading margin of 3 dB, and an appropriate SNR of 15 dB, the necessary maximum transmission power of an RNT or RBS will be in the range of up to 71 dBm if there are no antenna gains (see Table 8.5). It can be reduced by both, the transmitting and receiving antenna gain value since the path loss value will decrease by these gain values.

Power Control For FWA networks, it will be suitable to apply power control to the RBS and RNT transmitters, at least for the uplink point-to-point data transmission. The transmission power calculation presented in the last section refers to full cell site coverage. RNTs at locations close to the RBS can work with significantly lower signal powers and reducing their transmitter power and the respective power at the RBS will reduce the overall system interference.

The simulations will consider power control depending on the path loss value of the link between the RNTs and their belonging RBS. Hence, the transmitting power $P_{Tx(\mathrm{PC})}$ with power control applied is individually reduced to

$$P_{Tx(\mathrm{PC})} = \min\{P_{\max},\ P_{\mathrm{req}} + L_{\mathrm{PL}}(d = d_{\mathrm{Link}})\}, \tag{8.6}$$

where $P_{\max}$ is the maximum transmitting power to overcome the maximum path loss at the cell edge and $L_{\mathrm{PL}}(d = d_{\mathrm{Link}})$ is the path loss value of the respective link. As a result all the received signals have the same power level at the receiver as long as the maximum transmitting power offers the required level [3].

Received Signal Power The FWA network being analysed for direct sequence CDMA is assumed to behave power controlled. This means that in every radio cell each RNT signal arrives at its respective RBS with the same received power level. The received signal power value of -78 dBm is assumed for the three different scenarios to be investigated. This value is taken over from the equivalent TDMA FWA network simulation campaign for the same scenario.

Modulation Following the proposal of the *Digital Audio Video Council* (DAVIC) for the *Local Multipoint Distribution System* (LMDS) transmission technology, two modulation schemes shall be applied in FWA networks, QPSK and 16 QAM. The choice of the modulation technique to be employed will depend on the current link quality, e.g. the *Signal-to-Noise Ratio* (SNR) of the connection. For sake of simplicity the modulation technique here is restricted to QPSK.

Interference The system itself or systems of other operators using the neighbouring frequency range causes interference which can be treated as additional noise.

Interference consists of *Inter-Channel Interference* (ICI), *Adjacent Channel Interference* (ACI), and *Co-Channel Interference* (CCI). The first is a result of delayed signal parts which are caused by multipath propagation or failed synchronization of the receiver. ACI considers the overlapping parts of the frequency spectrums of neighbouring frequency channels, either in the same system or of different systems. CCI is calculated during the simulations considering all current connections established within the same time interval and frequency channel. Therefore, a carrier signal power has to be provided significantly higher than theoretically derived from the link level, e.g. coding performance analysis to offer a sufficient *Packet Error Ratio* (PER) over the whole radio cell.

Inter-Cell Interference The calculation of the interference caused by neighbouring radio cells to a reference cell is necessary for the capacity equations developed for the multi-cellular CDMA system.

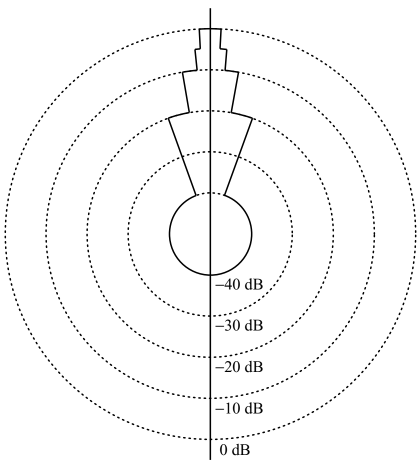
The inter-cell interference can be computed using the geometric position of the RNT and RBS in the scenario when power control is applied. The summation of these values give the total other cell interference present in the reference cell. This I_{inter}, however, results from the assumption that all terminals are always active. This is not quite correct as the terminals defined by the traffic model presented below are only active for a certain time T_{on} and they are idle during the time T_{off} otherwise. During T_{on}, each RNT generates cells at a mean cell rate of 5 %. This activity of the RNT determines the interference it causes.

$$I_{\text{inter}} = \sum I_{ij} \cdot 5\,\% \cdot \frac{T_{\text{on}}}{T_{\text{off}} + T_{\text{on}}} \tag{8.7}$$

The I_{inter} values in Table 8.4 are calculated for scenarios with different antenna arrangements. The I_{inter} values are relative to the received signal power P_i of a power controlled RNT to its serving RBS in the reference cell. The values for the time intervals deciding the activity are taken for the equivalent TDMA FWA network with 30 % average traffic offer per RBS in a radio cell.

Antenna Patterns The FWA network fixed-to-fixed radio link allows the deployment of high-gain directional antenna at the user's houses as well as sectored antennas at the base stations. This can improve signal strength and reduce interference. The following antenna characteristics summarized in Table 8.5 will be used in the investigation.

Due to the use of directional or beam antennas at the RNT side, only a few RNTs of a given scenario cause interference referring to a specified location, either an RBS or RNT. Suppose the additional loss $L_{\text{Antenna}}(\alpha)$ of an RNT antenna with beamwidth $\delta = 2\delta_0$ is given by



$$L_{\text{Antenna}}(\alpha) = \begin{cases} L_0 & |\alpha| \le \delta_0 \\ L_1 & \delta_0 < |\alpha| \le \delta_1 \\ \vdots & \vdots \\ L_s & \delta_{s-1} < |\alpha| \le \delta_s \end{cases} \tag{8.8}$$

where is the angle between the *Line of Sight* (LoS) path, which will be the antenna beam justification, and the direct link line to another terminal. $L_0 = 0\,\text{dB}$ should be convenient, since the antenna gains G_{RNT} or G_{RBS} of the link participating stations are already included in the free space propagation formula Equation (8.5), and the s values for L_i and δ_i, respectively, should consider the beam form of the RNT antenna as depicted in Equation (8.8). Note that for increasing s the modelling of the RNT beam antenna becomes more detailed as the value of s defines the number of degree intervals within the antenna pattern associated with different losses L_i with $i = 1, \ldots, s$.

For exact simulations the number and position of all active terminals at a given moment have to be taken into account to calculate the currently engendered interference. Hence, the propagation path loss L_{PL} of each link between two terminals is amended by the beam antenna characteristic of the sending as well as the receiving terminal, considering the angles α_1 and α_2 between that link and both connections to the terminals associated RBS(s).

Table 8.4 Total other cell interference

Scenario	T_{on}	T_{off}	I_{ij}	I_{inter}
Omnidirectional	10 s	70 s	505.62	3.096 P_i
Narrowbeam	10 s	70 s	13.81	0.086 P_i
Sectored	10 s	70 s	11.60	0.073 P_i

Table 8.5 Antenna characteristics

	RBS Antenna		
	Omnidir.		Sectored
Parameter	RNT Antenna Omnidir.	RNT Antenna Direct.	RNT Antenna Direct.
RBS Tx Power [dBm]	71	42	30
RBS Antenna Gain [dBi]	0	0	12
δ_0, L_0	–	–	30, 0
δ_1, L_1	–	–	35, 5
δ_2, L_2	–	–	40, 10
δ_3, L_3	–	–	50, 20
δ_4, L_4	–	–	180, 40
RBS Tx Power [dBm]	71	42	30
RBS Antenna Gain [dBi]	0	29	29
δ_0, L_0	–	3, 0	3, 0
δ_1, L_1	–	5, 5	5, 5
δ_2, L_2	–	10, 10	10, 10
δ_3, L_3	–	20, 20	20, 20
δ_4, L_4	–	180, 40	180, 40

Table 8.6 summarizes the system parameters considering transmission techniques and radio aspects.

8.3.3 Coding Aspects

Following the proposal of DAVIC for LMDS systems [2], ATM data cells should be protected with a *Forward Error Correction* (FEC) mechanism. A shortened *Reed-Solomon Code* (RSC) is applied to each packet data unit. For further information please refer to S. Mangold and I. Forkel [7].

8.3.4 Traffic Aspects

The comparison of TDMA and CDMA is based on two different traffic models. The simulated TDMA system is a packet switched system whereas the analysis for CDMA is centred around a circuit switched system.

8.3.4.1 TDMA Packet Switched Traffic Model

In order to enable the modelling of realistic ATM traffic within the simulated multi-cellular FWA networks, the characteristics of the used PDU-sources are discussed in this section.

Each RNT is defined by a fixed position, its link to one RBS and various statistical traffic parameters. In order to understand the outcome of the simulations and the

Table 8.6 Radio parameters

Parameter	Value
Frequency [GHz]	28.5
Bandwidth [MHz]	56
Frequency Bands	4
Modulation	QSPK
Propagation Coefficient	2.7
Path Loss at 1 m [dB]	61.55
Path Loss at Edge of Coverage [dB]	150.67
Fading Margin [dB]	3.0
Receiver Noise Figure [dB]	5.0
Background Noise [dBm]	−97.5
Adjacent Channel Interference [dB]	$-60 \cdots -40$
Received Signal Power [dBm]	−78

manifold effects of the resource allocation, cell scheduling, multiplexing, cell delays, congestion between the competing RNTs at RACH and various other techniques, *Available Bit Rate* (ABR) traffic only will be modelled rather than mixed multimedia services with *Constant Bit Rate* (CBR), VBR, ABR and *Unspecified Bit Rate* (UBR) service classes. ATM cells and their respective MAC-PDUs are generated for uplink and downlink, where at each single RNT the traffic is modelled as a full uplink or downlink stream, not mixed. The asymmetric offer will be provided by allowing both types of RNTs communicating simultaneously. The different activities of the individual RNTs define the asymmetric offer per RBS.

An asymmetric average offer of 1:4 (up/down) as well as a symmetric average offer of 1:1 will be simulated. A cell arrival means also the arrival of one MAC-PDU at the RNT or RBS queues and is referred to as *Cell Reference Event* (CRE).

Figure 8.4 illustrates a scenario configuration with four simultaneously active RNTs, two with uplink and two with downlink MAC-PDUs.

An RNT is characterized by one ABR connection, alternating between active and idle period times. A generative state model is applied to define these random period times, see Figure 8.5. Both, active and idle times are negative exponential distributed random numbers. Typical mean times are $T_{on} = 10\,s$ and a varying T_{off} between 1 s and 150 s, where T_{on} is the time the model is in state active and T_{off} means the time the model is in state idle. Applying traffic models for the RNTs in which terminals are sometimes active

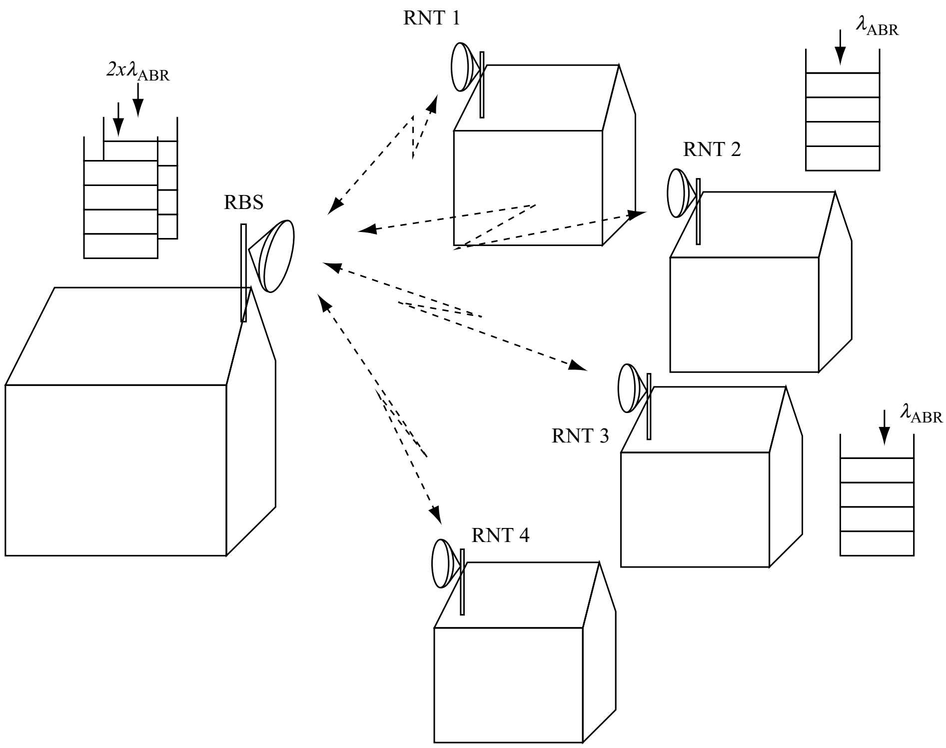


Figure 8.4 PDU sources modelling plain ABR traffic with Poisson arrivals. One connection per RNT is assumed with either uplink or downlink traffic

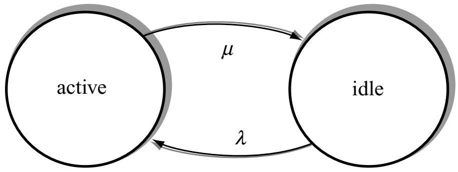


Figure 8.5 Traffic model for one RNT

and sometimes silent, leads to time-varying interference situations and capacity demands where hot spot areas occur randomly on arbitrary locations.

During active phases, the connection is characterised by Poisson arrivals of cells in up- or downlink, indicated in Figure 8.5. All stochastic generators for these CREs work independently of each other.

The traffic offer must be varied within the simulations in order to find and determine the system capacity limits with FCA and DCA schemes. In the simulations, this will be ensured by varying the mean idle time of all RNTs. Each connection is defined to use a certain amount of the maximum available capacity of one RBS which is defined as the maximum capacity of one frequency. Note that at the RBS one single transceiver is used which means that only one frequency channel can be operated simultaneously.

The overall system capacity highly depends on the fact that a connection is dropped if a certain threshold in the PER, e.g. 5 % is exceeded. As a matter of fact, the gain from statistical multiplexing is reduced if a small number of active connections (or active RNTs) per RBS, each with a relatively high traffic offer, is assumed rather than a large number of connections where the individual connections contribute to the overall traffic only a little [6].

The following simulation parameters of Table 8.7 define the traffic sources.

If the downlink to uplink ratio is 1:1, all RNTs are assigned to the same mean idle time T_{off}. The offer per RNT, i.e. the offer per virtual connection with respect to the total offer to one radio cell is given by the following equation. The equation is still valid when sectored cells are introduced.

$$\lambda_{\mathrm{ABP}}(\mathrm{RNT}) = \frac{T_{\mathrm{on}}}{T_{\mathrm{on}} + T_{\mathrm{off}}} \cdot \mathrm{MCR} \tag{8.9}$$

8.3.5 Parameters of the Resource Unit DCA Technique

The channel allocation technique of the simulations is based on the resource unit principle that was already presented above The parameters of the resource unit principle are found in Table 8.8. These parameters will be constant for all simulations. However, the duration of a slot can be modified to acknowledge the effect of the modulation schemes QPSK or 16 QAM.

The tolerable packet error ratio is set to 5 %. If this value is surpassed, the RBS tries to allocate a new resource unit for a better transmission. If a resource unit replacement cannot be found the *Cell Loss Ratio* (CLR) increases and finally connections are dropped. To avoid too many erroneous transmissions an *Automatic Repeat reQuest* (ARQ)

Table 8.7 Parameters for the traffic sources

	Source	Remark
Type	ABR	applies ARQ, typical multimedia
max. CTD	30 ms	minor real time demands
Generator	Poisson	uncorrelated arrivals
	State Model	Remark
mean T_{on}	10 s	Negative exponential distributed
mean T_{off}	1 s . . . 150 s	random times defines traffic offer of particular connection
	ATM Cell Reference Events	Remark
Cell rate per conn.	up to 1633/s	48 RNT/radio cell lead to overload if all active
MCR[1]	5 % (during active periods)	in percentage of overall system load
$\mathrm{MCR}_{\mathrm{min}}$	0.9 MCR	the individual connecttion vary
MCR	1.1 MCR	slightly in their MCR characteristics

[1] Mean Cell Rate.

Table 8.8 DCA parameters

Parameter	Value
Frequencies	4
No of Resource Units per Frame	21
Resource Unit Length [slot]	5
Slot Duration [μs]	28.6
Transceiver Turn Around Time	0
FCA Cluster Size	7 or 12
MAC signalling period length [slot]	15
Interference Threshold [dBm]	−87

protocol can be switched on at the beginning of a simulation campaign. The ARQ protocol can improve the CLR at the cost of increasing the cell delay.

The reservation and allocation of a resource unit is performed by the RBS. The RBS measures the interference level of the resource unit it wants to employ. If the measured interference level is above a threshold value, the RBS considers the resource unit to be already in use and a replacement resource unit is searched for. The interference threshold

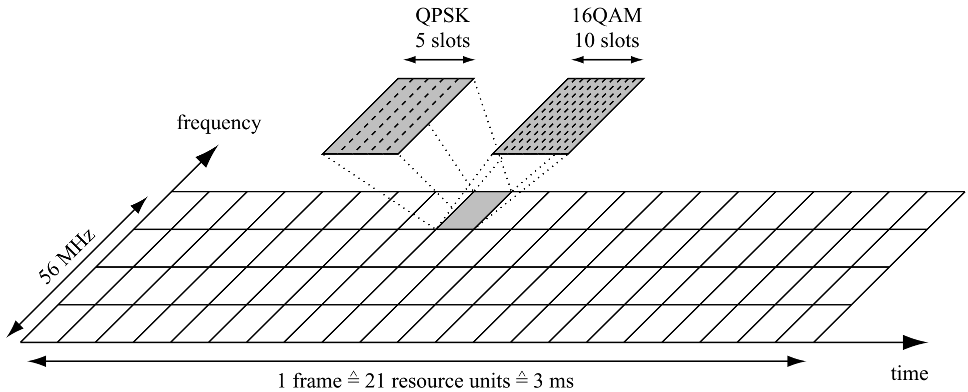


Figure 8.6 Resource unit principle of the DCA scheme

value selected for the simulations is determined by the transmission powers, the attenuation due to the path and the background noise.

The structure of the physical channel or, in other words, the TDMA frame configuration is presented in Figure 8.6. Also depicted is the influence of the modulation scheme. Based on this model for the physical channel, the simulations of the DCA scheme for FWA networks have been performed.

8.4 Simulation Results of DCA in FWA Networks

Presented here are the results of the simulations performed for DCA in FWA networks with the parameters defined above. After a brief description of the evaluation criteria, different enhancing technologies to improve the DCA performance are introduced and their effect on the system is commented. At the end of the chapter a capacity analysis is performed based on the quality of service offered by each system.

8.4.1 Criteria for Evaluation of the Simulation Results

To determine the quality of DCA in FWA networks, measurements of the system behaviour and the *Grade of Service* (GoS) with respect to blocked and dropped MAC connections are assessed. In addition, the cell loss ratio, cell transfer delays and when appropriate the C/I ratios are evaluated.

At each terminal, individual carrier and interference values are measured leading to a particular loss ratio of MAC-PDUs. One lost MAC-PDU results in the loss of a single ATM cell and assuming that retransmissions are required if ARQ is used, this will increase the transfer delay of the respective cell. The loss ratio depends on the error characteristics and the applied transmission and coding techniques, in other words, on the characteristics of the physical layer.

8.4.2 Simulation Results

During the initial simulations, the simulation parameters had to be verified. Of particular interest were the optimum transmission powers of the stations and the interference threshold upon which the availability of a free resource is determined.

Conducting a simulation strategy based on analytical assumptions without considering any antenna gains at the station sites the following values were attained:

- Transmission power of 71 dBm at both, the RNT and RBS.
- Interference threshold value of −87 dBm.

This transmission power is unrealistic as GaAs amplifiers cannot dispend such a high energy. But the application of realistic antennas allow to operate the transceivers at much lower power levels than assumed in this primarily simulations.

Following now are the results of a simulation campaign in which an attempt was made to analyse different capacity enhancing technologies for radio transmission in FWA networks.

8.4.2.1 FCA Simulation

FCA simulations were carried out with cluster sizes of 7 and 12. Figure 8.7 shows the scenario with a 7 cluster. The darker shaded region shows the radio cells that share the same radio resource units. Since there are 4 frequencies each with 21 resource units, 12 resource units are assigned to each radio cell among the seven radio cells in the cluster. Since 21 resource units are available in each frequency band accessible with one transceiver, the maximum achievable traffic load in the system is around 55 %. Such a high load cannot be reached with the chosen dynamic traffic models and is also reduced by system interference.

Furthermore, a cluster size of 12 as illustrated in Figure 8.8 was selected for the simulations based on the following premise. Assuming that an RBS is able to carry a

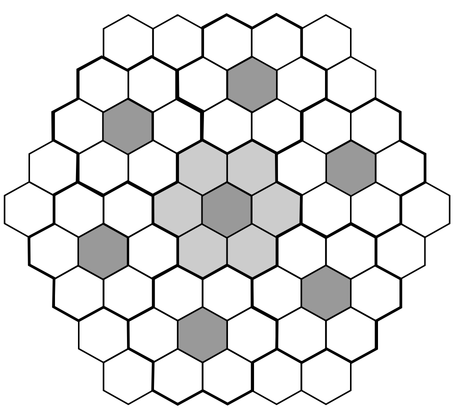


Figure 8.7 Scenario with cluster size 7

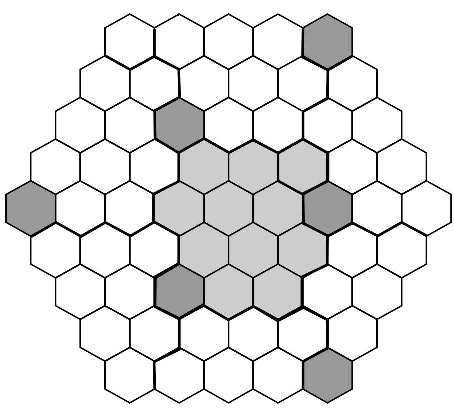


Figure 8.8 Scenario with cluster size 12

traffic load of 33 %, an RBS would require a capacity of almost one third of a frequency band, hence 3 RBSs could share one frequency band. Since the system is divided into 4 frequency bands, 12 RBSs could be served simultaneously accessing the overall system capacity which results in a 12 cluster. Dividing the resource among the radio cells of a 12 cluster, each radio cell is assigned 7 resource units. Indeed, the simulation campaign with a cluster size of 12 showed slightly better results than the counterpart with a 7 cluster.

Notable for these simulations was the very low traffic load that could be carried by the systems. Due to the high dynamic of the applied traffic models, the FCA prematurely reaches its capacity limit since all available resources have already been allocated. That happened also at a comparatively low amount of offered traffic. An increased number of blocked connections results out of this. Moreover, since FCA has no mechanism to provide transmission quality to the connections, a high PER has been noticed in the simulations for the smaller cluster size 7. Because of the shorter re-use distance, the co-channel interference increases in this scenario compared to the cluster size 12 system.

8.4.2.2 Simple DCA Scheme

These primary DCA simulations were carried out using the basic DCA scheme parameters explained in the section before. Compared to the FCA simulations there was a considerable increase in traffic that could be carried in the system.

With a traffic load of 26 % per RBS all connections were admitted into the system and all data packets were carried without transmission errors. Increasing the traffic load leads to a degradation of the system quality as proven later. Consider the number of rejected and aborted calls given in Table 8.9.

The effect that there are more aborted calls than rejected calls can be explained by the nature of the DCA technique. A connection is rejected only if the interference level measured on the resource unit is above the threshold value defined in the DCA parameter table. This threshold is a free parameter and is here set up to maximize the number of connections, on the expense of the larger number of dropped resource units. If a connection is established it can happen that the quality of the resource unit is so poor that the packet error rate exceeds the tolerance level of 5 %. The allocating entity (here the RBS) searches for a replacement for this resource unit, dropping the connection if the search fails.

Table 8.9 Simulation results for the simple DCA

Offered Traffic	Blocked Calls	Aborted Calls
26 %	0.00 %	0.00 %
28 %	0.00 %	0.02 %
30 %	0.00 %	0.06 %
32 %	0.02 %	0.07 %
34 %	0.01 %	2.04 %

The nature of the properties of the DCA scheme with varying traffic load are shown in the figures below. As shown in Figure 8.9 the SNR or C/I level decreases with increasing traffic. This is evident since the transmission power of the RNTs is constant whereas the interference is raised through the increased activity of the transmitting stations. Similarly the number of allocated containers increases if more traffic has to be carried. This effect is seen in Figure 8.10.

8.4.2.3 DCA with ARQ

One method to improve the quality of the DCA scheme with respect to CLR is the application of an ARQ protocol. The ARQ protocol requests the retransmission of a

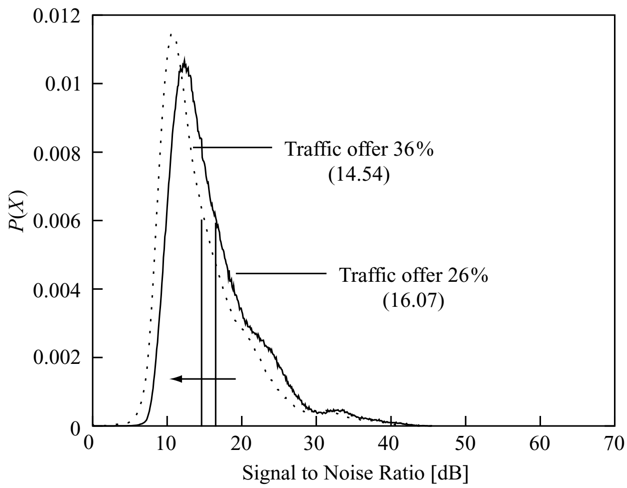


Figure 8.9 SNR for DCA uplink

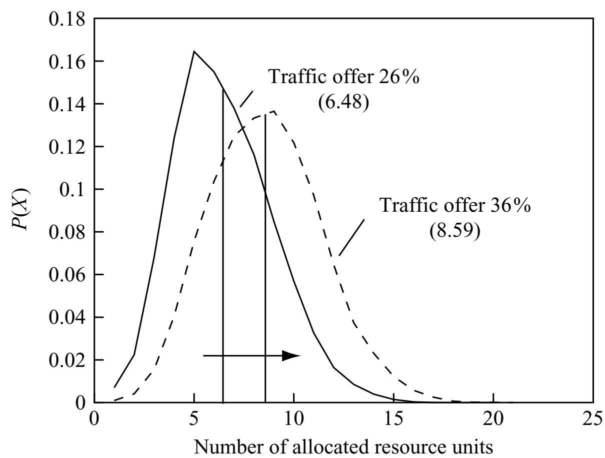


Figure 8.10 Mean number of allocated resource units

packet if it is identified as being faulty at the receiver. Thus, ARQ improves the CLR at the site of the receiver. However, since packets must be re-transmitted, the waiting time for packets to be serviced increases. This can lead to longer cell delays, a situation which might be intolerable for time critical service classes like CBR which have stringent values for the maximum tolerable cell delay. Comparing the cell delays of the previous simulation and the one with ARQ there is a notable difference. Figure 8.11 shows the juxtaposition of the cell delays for a traffic load of 34 % at the RBS. The simple DCA scheme has a mean cell delay of 51 slots which equals 1.46 ms. Moreover, the probability for delay values larger than 20 ms can be neglected. The DCA scheme with an ARQ protocol has a mean cell delay of 120 slots corresponding to 2.92 ms where almost 3 % of the packets exceed a delay of 20 ms.

As an effect of the cell retransmissions that take place (which means additional traffic), the interference in the system increases and the traffic load that could have been carried decreases.

8.4.2.4 DCA with Asymmetric Traffic

Operating DCA with asymmetric traffic is not a capacity enhancement technique. It is interesting, however that the DCA technique performs slightly better for a realistic asymmetric traffic distribution than for a symmetric distribution, whereby the resulting overall traffic load is the same for both cases. Considering the traffic model, the offered traffic is determined by a T_{on} time and a T_{off} time. The mean T_{on} for a connection is 10 s. Adjusting the mean T_{off} time of the connection the traffic offer λ_{ABR} (RBS) of an RBS can be determined.

$$\lambda_{\mathrm{ABR}}(\mathrm{RBS}) = \sum_{i=1}^{n_{\mathrm{RNT}}} \frac{T_{\mathrm{on_i}}}{T_{\mathrm{off}} + T_{\mathrm{on}_i}} \cdot \mathrm{MCR}_i \tag{8.10}$$

where MCR_i is the mean cell rate of a single connection i and n_{RNT} is the number of RNTs present in one radio cell (here equal to 48). The T_{off} calculated here is valid for

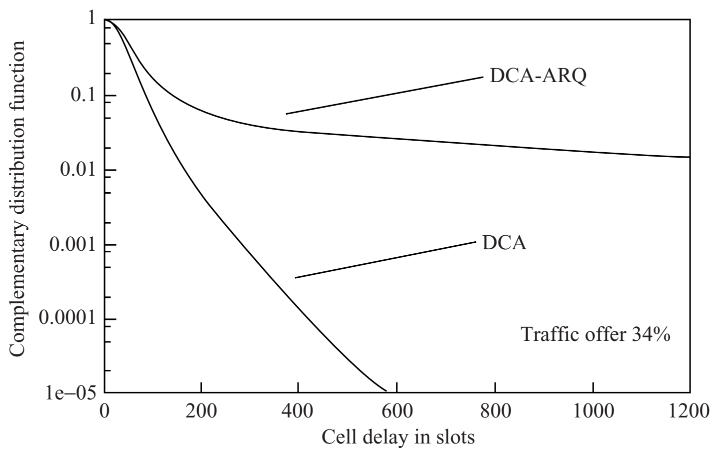


Figure 8.11 Comparison of cell delay

RNTs on the uplink and the downlink for a ratio of 1:1. To adjust an asymmetric load of, for example, 1:4 for uplink to downlink, where there is an equal number of terminals operating on the uplink and the downlink, the following calculation can be done:

$$\lambda_{\mathrm{ABR}}(\mathrm{RBS}) = 24 \cdot \frac{T_{\mathrm{on,DL}}}{T_{\mathrm{off,DL}} + T_{\mathrm{on,DL}}} \cdot \mathrm{MCR}_{\mathrm{DL}} + 24 \cdot \frac{T_{\mathrm{on,UL}}}{T_{\mathrm{off,UL}} + T_{\mathrm{on,UL}}} \cdot \mathrm{MCR}_{\mathrm{UL}} \qquad (8.11)$$

Considering $T_{\mathrm{on,DL}} = T_{\mathrm{on,UL}} = T_{\mathrm{on}}$ and $\mathrm{MCR}_{\mathrm{DL}} = \mathrm{MCR}_{\mathrm{UL}} = \mathrm{MCR}$ the asymmetry condition is

$$\frac{1}{4} = \frac{T_{\mathrm{on}} + T_{\mathrm{off,DL}}}{T_{\mathrm{on}} + T_{\mathrm{off,UL}}} \text{ which leads to } T_{\mathrm{off,UL}} = 3T_{\mathrm{on}} + 4T_{\mathrm{off,DL}} \qquad (8.12)$$

Thus, for the downlink the capacity can be determined by the $T_{\mathrm{off,\,DL}}$ time derived indirectly from Equation (8.13)

$$\lambda_{\mathrm{ABR}}(\mathrm{RBS}) = T_{\mathrm{on}}\left(\frac{30}{T_{\mathrm{on}} + T_{\mathrm{off,DL}}}\right) \cdot \mathrm{MCR} \qquad (8.13)$$

and similarly for the uplink from Equation (8.14)

$$\lambda_{\mathrm{ABR}}(\mathrm{RBS}) = T_{\mathrm{on}}\left(\frac{120}{T_{\mathrm{on}} + T_{\mathrm{off,UL}}}\right) \cdot \mathrm{MCR} \qquad (8.14)$$

The traffic model can be understood as if 30 RNTs (half of them, 15, in downlink) with a high traffic load or 120 RNTs (60 in uplink) with a low traffic load would generate the same traffic at an RBS as 48 RNTs (thereof 24 in each direction, downlink and uplink) operating at a medium traffic load. The asymmetry has been implemented in the system in order to evaluate the DCA behaviour with respect to such an asymmetric traffic. The results are presented in the final comparison of all the investigated technologies at the end of this section.

8.4.2.5 DCA with Power Control

The intention behind power control is to overcome the so-called 'near–far' problem. The strong signal received at the cell site from a near-in RNT will mask over the weaker signal from a far-out RNT if both transmit with the same power. Applying power control, the transmitting powers of each station can be adjusted so that the received signal power at the radio cell site is the same from all RNTs and vice versa. There are two different methods of achieving power control. A primitive method is the adaptation of the transmitting power during installation of the system. The adaptation is calculated on the basis of the path loss model. A more sophisticated adaptive power control method can be accomplished by regulating the current transmitting power of each transmitting station according to the current C/I level of its respective connection. For the DCA power control simulation the simpler method was used. Considering the stationary nature of the RNTs in a FWA network scenario this strategy seems appropriate.

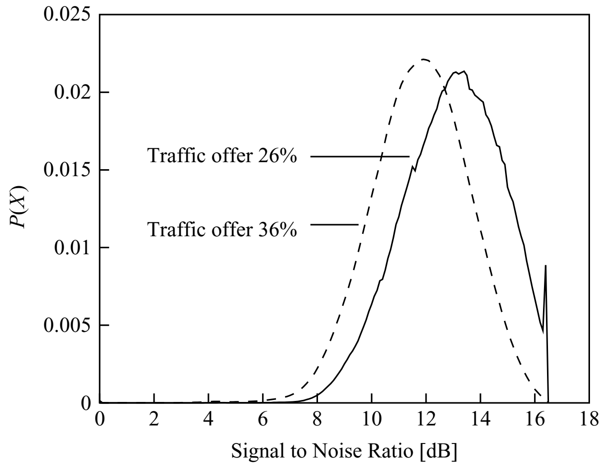


Figure 8.12 SNR in the power controlled system

Figure 8.12 shows the SNR curves for the uplink from RNT to RBS at two different traffic loads. Once again it can be seen that increasing the capacity required at the RBS, the SNR decreases. The employment of power control can be seen in the progression of the curve for an RBS capacity of 26 %.

The highest possible SNR in the system is now 16.5 dB. This value can be explained by the following argument. The required received power level at each station is set to −78 dBm. Considering a background noise level of −97.5 dBm (see the radio parameters) and an additional fading margin of 3 dB exactly this SNR value of maximally 16.5 dB results for the radio cell in the case that no interference is present on the channel.

Comparing this value to the values in Figure 8.9 this maximum SNR is quite low. However, the adjusted received signal strength guarantees that the level of interference in the system is suppressed. Reducing the interference level in the radio cell has two effects. The amount of traffic that can be carried within a radio cell rises. Secondly, the PER is reduced significantly. Comparing the PER for the simple DCA scheme with the power controlled scheme, there is an almost three-fold advantage when the PER for the former is 0.05 and the PER for just DCA is 0.15 for a system operating at 34 % traffic load. Plotting the PER against the radio cell radius, another interesting effect can be observed.

As can be seen in Figure 8.13 the PER is almost constant over the distance of an RNT from its RBS. This observation is conform to the purpose of the power control technology. Also noticeable is that the PER increases for the RNTs located at a distance of more than 1800 m from the RBS. The PER increases for these terminals because their received transmission power strength is below that of the predetermined level of −78 dBm. As a result these RNTs have a lower SNR at the RBS than the nearer RNTs.

The overall interference in the system has been suppressed at the cost that the far RNTs may have transmission errors. Also shown in Figure 8.13 is an imbalance between the PER for the downlink when compared to the uplink. The imbalance is due to the fact that the resource allocating entity is in the RBS. For transmissions on the uplink the RBS selects those resource units which are suitable for itself. However, while transmitting on the downlink the RBS selects resource units which may not be optimal from the point of view of the RNTs. Figure 8.13(b) shows how the PER increases in this case.

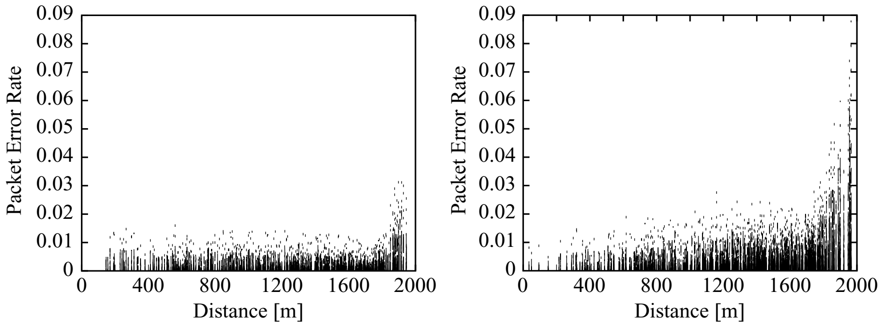


Figure 8.13 Mean PER for the uplink (left plot), mean PER for the downlink (right plot)

8.4.2.6 DCA with Directional Subscriber Antenna

Until now all simulations were performed with omni-directional antennas at the RNTs and the RBSs. Mitigation of interference was achieved by using power control. A further and more efficient reduction of interference is achieved if directional narrowbeam antennas are placed at the RNT sites.

For the simulations the antenna characteristics were selected according to the values contained in Table 8.5. Beneath the reduction of transmission power due to the high antenna gain of 29 dBi, the main signal component will be transmitted to the RBS and is not emitted in other directions.

The installation of narrowbeam antennas therefore leads to a reduction of interference, thereby increasing the SNR in the system. Raising the signal strength should culminate in a higher capacity utilization of the RBS and a reduced PER.

Figure 8.14 shows the comparison of the SNR value distribution between the simple DCA scenario and network employing directional antennas at the RNTs. The DCA simulation referenced here was simulated with a traffic capacity of 32 % while the simulation with directional antennas was performed with 42 % traffic load. Both systems showed similar performance of rejected and aborted connections at these traffic loads. The afore mentioned SNR improvement between the two schemes is also showed in Figure 8.14.

Due to a significantly lower number of possible interferes involved, the scattering of the SNR values is very high. Measuring a mean SNR for simple DCA at 15 dB and a mean SNR of 21 dB for the enhanced technique, an increase of 6 dB sets in.

Considering the results of the power control scheme, an even greater capacity enhancement should be achievable if power control is applied to the DCA scenario with narrowbeam antennas. This optimized scheme will be discussed later.

8.4.2.7 DCA with Sectored Cells

Sectoring at the RBS site allows a further reduction of transmission power and therefore also a suppression of overall system interference. The installation of high-gain antennas at both the RNT and RBS that means coupling sectored RBS antennas and narrowbeam RNT antennas mitigates the interference experienced by stations located beyond the opening angles of these antennas.

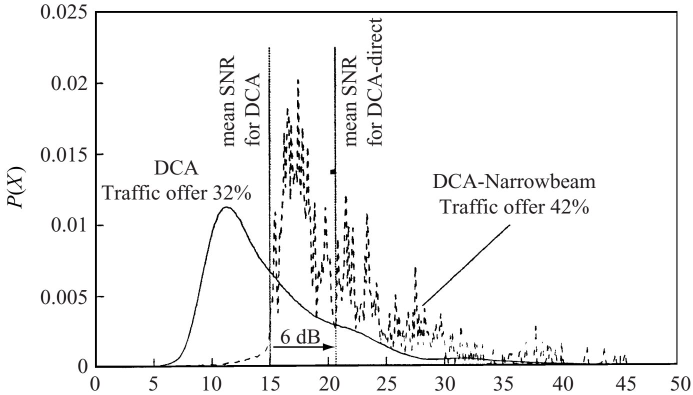


Figure 8.14 SNR for narrowbeam RNT antennas

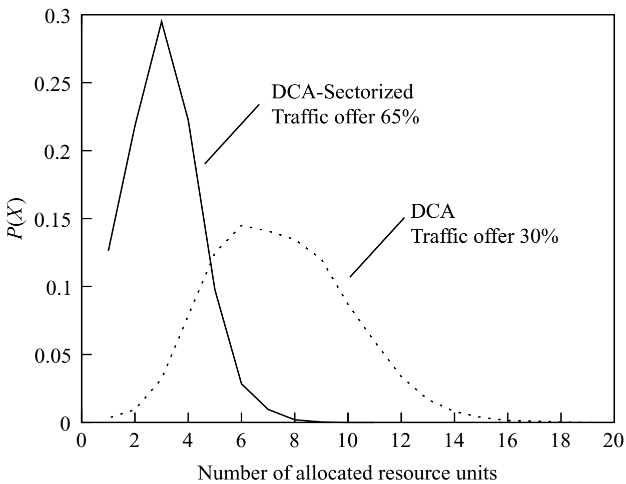


Figure 8.15 Allocated resource units

Sectoring is performed by splitting a radio cell into multiple pie shaped wedges. In the simulator each sector is considered as an independent radio cell with its own self-organizing RBS. Hence, from a technical point of view, the number of somehow virtual RBSs in a hexagonal radio cell increases according to the number of sectors in this radio cell.

The error performance improves greatly for a DCA scheme with sectored antennas. The mean PER stays at 0 in the sectored system for traffic offers up to 25 %. Note that the traffic offer has to be considered at each virtual RBS, e.g. each sector of the radio cell. Compared to the simple DCA scheme with a capacity of 30 % the sectored system is able to carry more than 150 % traffic. This is possible, because the same frequencies which means the same part of the radio capacity can be reused within the same cell by different sectors. With the traffic model assumed for the simulation it was not possible to estimate the limit of the sectored FWA scenario.

8.4.3 Capacity Analysis of FCA and DCA for FWA Networks

The capacity analysis for the mentioned DCA schemes can be based on the major parameters mean SNR and the GoS accomplished in the systems.

8.4.3.1 Mean SNR

It is commonly expected that system performance increases with steadily rising SNR. However, this is not quite correct in the case for FWA networks.

Figure 8.16 gives an overview of the mean SNR values plotted against the simulated traffic loads for the different schemes. Here, it can be observed that power controlled DCA which can carry more traffic than simple DCA has a lower mean SNR. Similarly, FCA with a cluster size of 12 has a higher mean SNR than DCA although it can carry less traffic.

Apparently, the overall interference level in the system also plays a very important role in allocating capacity. Power controlled DCA has a low mean SNR but simultaneously also a low interference level in the system since the transmission power of the stations is reduced with respect to the other schemes. The FCA schemes lose capacity because the interference in the co-channel cells is too high. Striking is the extreme increase in SNR through the use of narrowbeam antennas at the RNT station sites, which is a result of the highly directional antennas emitting only 2.3 % of the power compared to an omni-directional antenna. Therefore, although the average transmission power is similar for all schemes, the mitigation of interference is by far highest in the scenarios with high-gain antennas.

8.4.3.2 Grade of Service

The second parameter for defining the capacity which can be offered by an RBS is its GoS. The GoS is defined by

$$\text{GoS} = \frac{\text{nos. of rejected calls} + (10 \times \text{nos. of aborted calls})}{\text{total number of calls}} \tag{8.15}$$

The number of aborted calls (also known as dropped calls) is weighted with 10 as this would mean that a terminal loses its connection while transmitting, a situation which is highly intolerable. A system should be operated at a GoS below 1 %. Figure 8.17 gives an overview of all the different DCA schemes that were simulated and their respective GoS performance.

It can be seen that FCA performs worse when compared to the DCA schemes. The notable difference is a little surprising concerning the very low amount of traffic that can be carried. The main reasons for this poor performance are the high co-channel interference levels that are present for small cluster sizes (≤ 7) or the little amount of available resources for large cluster sizes (≥ 12). Since the traffic model used for simulations generates a highly dynamic behaviour, call blocking becomes a severe problem for the FCA schemes which are unable to flexibly react on varying traffic conditions.

Interesting is also the observation that DCA performs slightly better than DCA with ARQ. This effect is due to the higher interference caused by the retransmissions of the

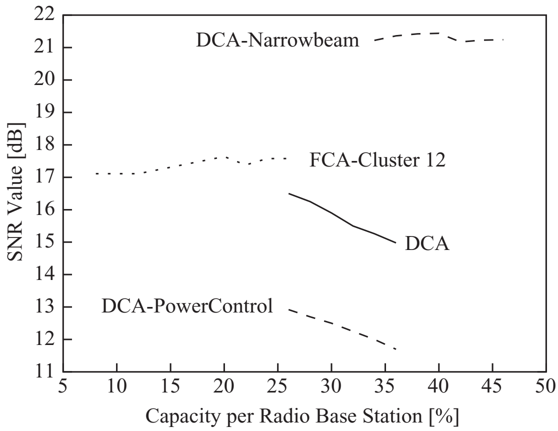


Figure 8.16 Mean SNR values

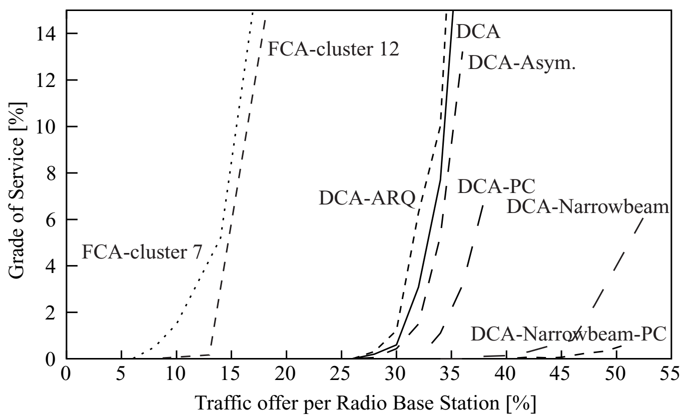


Figure 8.17 Comparison of GOS

ARQ protocol. A considerable raise in capacity is achieved if power control is applied. The power controlled DCA system can carry between 5 % and 6 % more traffic load at a comparable GoS. The application of narrowbeam antennas at the RNTs improves capacity by 14 % against the conventional DCA scheme. Considering the raise caused by the last two technologies it can be expected that a power controlled DCA scheme with narrowbeam antennas should lead to a capacity increase of around 20 % against just DCA. The highest gain in capacity per RBS is achieved by sectoring of an RBS and the employment of narrowbeam RNT antennas. This FWA network optimized technology leads to a gain of more than 80 % compared to the simple DCA scheme. If within the sectored scheme RNTs are allowed to measure the interference situation in resource unit an additional gain of around 2 % should be registered.

List of Abbreviations

ABR	Available Bit Rate
ACI	Adjacent Channel Interference
ARQ	Automatic Repeat reQuest
ATM	Asynchronous Transfer Mode
C/I	Carrier to Interference ratio
CBR	Constant Bit Rate
CCI	Co-Channel Interference
CD	Code Division
CDMA	Code Division Multiple Access
CLR	Cell Loss Rate
CRE	Cell Reference Event
CS	Channel Segregation
CTD	Cell Transfer Delay
DAVIC	Digital Audio Video Council
DCA	Dynamic Channel Allocation
DCS	Dynamic Channel Selection
DECT	Digital Enhanced Cordless Telephone
FCA	Fixed Channel Allocation
FD	Frequency Division
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FWA	Fixed Wireless Access
GaAs	Gallium Arsenid
GoS	Grade Of Service
HCA	Hybrid Channel Allocation
ICI	Inter-Channel Interference
LoS	Line of Sight
LMDS	Local Multipoint Distribution System
MADCAT	Mobile ATM Dynamic Channel Allocation simulaTor
MAC	Medium Access Control
MCR	Mean Cell Rate
PDU	Packet Data Unit
PER	Packet Error Ratio
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quaternary Phase Shift Keying
RACH	Random Access CHannel
RBS	Radio Base Station
RMS	Root Mean Square
RNT	Radio Network Terminal
RSC	Reed-Solomon Code
SNR	Signal-to-Noise Ratio
TD	Time Division
TDMA	Time Division Multiple Access
UBR	Unspecified Bit Rate

VBR Variable Bit Rate
VoD Video on Demand
WATM Wireless ATM
WLL Wireless Local Loop

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