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COMPUTER SIMULATION OF PERFORMANCE ENHANCING METHODS IN ATM BASED FIXED WIRELESS ACCESS NETWORKS

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ABSTRACT — **Capacity enhancing schemes for broadband fixed wireless access networks based on ATM are discussed. The simulation strategy is to evaluate the improvement of system performance by the application of different transmission technologies, such as power control or high gain antenna technology. Therefore, realistic traffic as well as radio propagation models for the respective scenario are introduced. Simulations have been carried out based on a dynamic channel allocation protocol developed at ComNets. Enhancing methods are added to the scenario subsequently and their performance is evaluated, step by step. Simulation results are presented, showing the gain in capacity due to the improved access schemes.**

I. INTRODUCTION

In the market of *Fixed Wireless Access Networks (FWAN)* companies enter the area of delivering broadband wireless multimedia services to the customers' premises. These companies need direct access to their customers without being dependent on the infrastructure of the present fixed network operators or spending time and money in digging up the roads to establish their own wired access system [1].

Based on statistics of the *International Telecommunications Union (ITU)* an enormous demand for fast access and quick installation exists, especially in the currently emerging countries with their more underdeveloped cable infrastructure. Communication systems will deliver various kinds of information services to an ever increasing number of customers. FWAN providing broadband services with capacity on demand have to meet the needs of future multimedia applications.

In this paper, a system description for an FWAN enabling access to broadband services is presented. As a key element, the concept is based on the wireless extension of *Asynchronous Transfer Mode (ATM)*, offering high scalability of bandwidth and capacity on demand for asymmetric and time-varying traffic. The definition of a scenario for computer simulation leads to a simulation campaign in which different enhancing technologies have been added and their improvement in system capacity and *Quality of Service (QoS)* has been proved.

The protocol stack including the *Dynamic Channel Allocation (DCA)* is based on the established *Dynamic Slot Assignment (DSA++) Medium Access Control (MAC)* protocol in combination with various *Logical Link Control (LLC)* protocols [2–4]. Whereas in [3] the DSA++ is evaluated with respect to a single cell fixed wireless access subsystem, we focus here on interference limited multi-cellular FWAN systems with their specific ability to apply high gain transmission technologies like fast power control and high gain directional antennas at the user's receiver side. The proposed system of the flexible FWAN and its parameters which must carefully be defined with respect to realistic scenarios are discussed in Section II. In Sections III, IV and V, simulations of plain DCA and combinations of power control and high-gain antenna technologies are presented, showing the effects of the proposed performance enhancing schemes for FWAN systems and their optimal configuration. A comparative overview of the technologies introduced is given in Section VI.

II. FWAN SYSTEM SCENARIO

The FWAN simulations are carried out with a hexagonal cell scenario containing 61 cells. One *Radio Base Station (RBS)* is placed in the center of each cell and 48 *Radio Network Terminations (RNTs)* are uniformly distributed over each single cell area. The inner 19 cells of this scenario are evaluated and the outer two rings of cells produce additional interference to achieve a realistic traffic and frequency usage for the simulation.

Cell Size Based on experiments conducted in San Francisco and nearby areas it was determined that the optimal FWAN for operation in the 30 GHz band has a cell radius of 2 km.

Propagation Model The path loss model implemented in the simulator is described by

$$L_{\mathrm{PL}}(d) = L_0 + 10n\log({}^{d}/{}_{d_0}) - \sum G_{\mathrm{Ant}}\,, \quad \text{with } L_0 = 20\log\frac{4\pi d_0}{\lambda}\,, \tag{1}$$

where G_{Ant} is the transmitter or receiver antenna gain, respectively, and n is the propagation coefficient. This coefficient models the propagation in different environments like urban, suburban, residential, or hilly terrain. Based on measurements in German urban areas $n = 2.7$ has been selected [5]. The reference path loss value in a distance $d_0 = 1\,\mathrm{m}$ is $L_0 = 61.545\,\mathrm{dB}$. This leads to a maximum path loss in distance $d = 2\,\mathrm{km}$ at the edge of coverage of $L_{\mathrm{PL,max}} = L_{\mathrm{PL}}(d = 2\,\mathrm{km}) = 150.67\,\mathrm{dB}$ if no antenna gain values G_{Ant} are considered. The path loss of all stations to each other are based on this path loss model.

Background Noise Considering a background noise power spectral density of $N_0 = 4\,{}^{\mathrm{pW}}/{}_{\mathrm{GHz}}$ [6] a noise level of -96.5 dBm for the entire licensed frequency band of 56 MHz is found. For our DCA configuration, in which the whole bandwidth is divided into four subbands, each frequency band of 14 MHz bandwidth is then disturbed by a noise level of -102.5 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 to the FWAN subscriber radio units and the RBSs. Including the receiver noise figure a background noise level of -97.5 dBm is finally adopted.

Interference The system itself or systems of other operators using the neighbouring frequency range cause 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 within the same system or out of different systems. CCI is calculated during the simulations considering all current connections established within the same time and frequency access unit, that means on the same channel.

The sum of interferences impairs radio transmission more severe than the background noise. Therefore, systems are evaluated with respect to their current *Signal to Interference plus Noise Ratio (SINR)*, whereby the impact on transmission errors of both parts is similar since they are treated as a certain amount of additional uncorrelated noise.

Transmission Power The optimal transmission powers of the RBS and the RNT depend on the attenuation of the radio link between the two stations, the interference noise level, and eventual antenna gains.

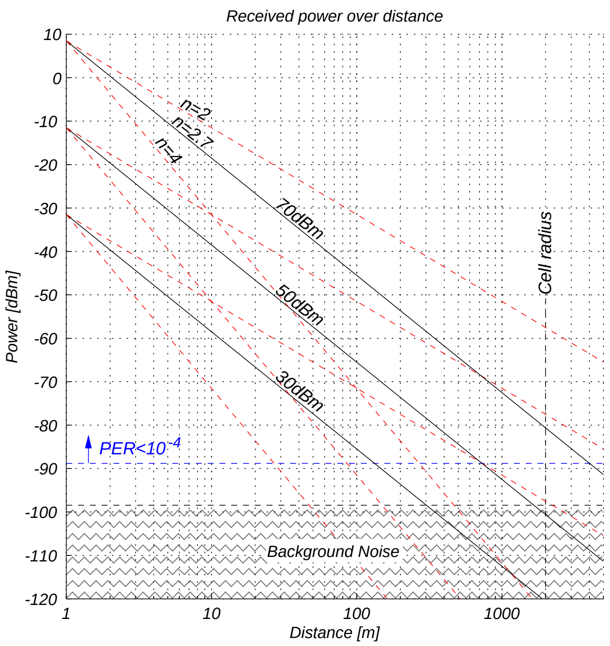

Figure 1: Received power versus distance to transmitter for FWAN scenarios, considering no antenna gains

In Fig. 1 the reduction of the received power with the distance from the transmitter is illustrated. The curves are obtained considering no antenna gains, neither for the transmitter nor the receiver antenna. A transmission power of 62 dBm offers an *Signal to Noise Ratio (SNR)* of about 9.3 dB even at the edge of coverage (at 2 km) and allows to cover the whole cell site with a *Packet Error Ratio (PER)* below 10^{-4} if QPSK modulation and an appropriate *Forward Error Correction (FEC)* as described below are used.

Including interference, a carrier signal power has to be provided significantly higher than theoretically derived above to offer a sufficient PER over the whole radio cell. The average transmission power of an RNT or RBS multiplied by the associated antenna gain values was determined in the range of 71 dBm.

Modulation and Coding Following the proposal of the *Digital Audio Video Council (DAVIC)* for the *Local Multipoint Distribution System (LMDS)* transmission technology [7], two modulation schemes are proposed for this FWAN, QPSK and 16 QAM. The choice of one of these modulation techniques or even others will depend on the current link quality, e.g., the SINR of the connection.

Furthermore, ATM data cells should be protected with a FEC mechanism. A $(63, 53)$ shortened *Reed-Solomon (RS)* code is applied to each packet data unit as described and evaluated in the following.

Like the ATM FWAN system presented here, the LMDS upstream is designed for carrying ATM traffic. RS coding is applied to each ATM cell. For the correction of five erroneous symbols within one cell, a systematic shortened $(63, 53)$ RS code is proposed.

For the evaluation of the coding performance, on the one hand a so-called Fritchman channel model used for link level simulations generates highly correlated bit errors. On the other hand, a *Binary Symmetric Channel (BSC)* disturbs the transmitted data by uncorrelated bit errors. The results are depicted in Fig. 2.

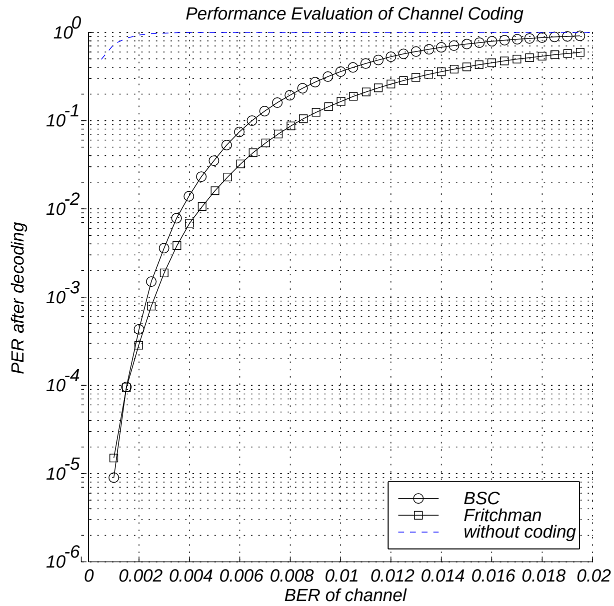

Figure 2: Packet error ratios after $(63, 53)$ RSC and the transmission over different channels

The RS code will offer higher performance if correlated errors appear on the transmission channel. The plots clarify the advantages of this code when the transmission errors are generated by the two-state Fritchman channel model. Compared to the BSC simulation results at the same mean BER, approximately only half of the coded ATM cells will be lost if correlated errors are generated by the channel, i.e., if the Fritchman model is used rather than the BSC. Nevertheless, LMDS coding was designed for radio channels with very low error probability which are expected for the FWAN environment. Allowing a PER of not more than 5 %, the channel must not generate more than 0.7 % bit errors with realistic correlation characteristics during transmission.

Traffic Models In order to enable the modeling of realistic ATM traffic within the simulated multi-cellular FWAN, the characteristics of the used sources are discussed in this section.

Each RNT is defined by a fixed position, its link to one RBS and various statistical traffic parameters. To understand the outcome of the simulations and the manifold effects of container allocation, cell scheduling, multiplexing, cell delays, congestions between the competing RNTs during random access, and various other techniques, *Available Bit Rate (ABR)* traffic only will be modeled rather than mixed multimedia services with CBR, VBR, ABR and UBR service classes. ATM cells are generated for uplink and downlink, where at each single RNT the traffic is modeled as a full uplink or downlink stream, not mixed. The asymmetric offer will be provided by allowing both types of RNTs communicating simultaneously. The activity of the individual RNTs defines the asymmetric offer per RBS.

An asymmetric average offer of 1:4 (up/down) as well as a symmetric average offer of 1:1 have been simulated. A cell arrival event means the arrival of one ATM cell at the RNT or RBS queues. Fig. 3 illustrates a scenario configuration with four simultaneously active RNTs, two with uplink and two with downlink sources.

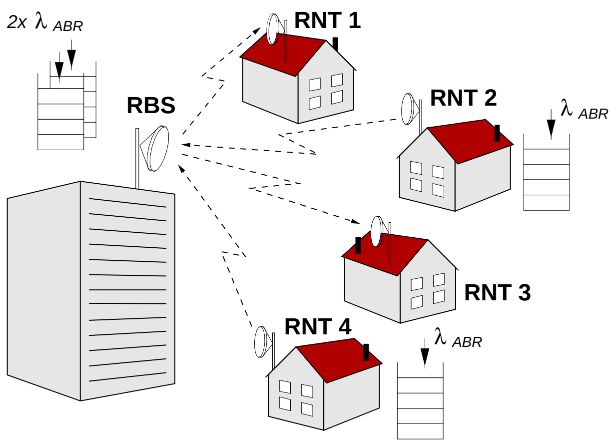

Figure 3: Traffic modeling with Poisson arrivals of ABR services

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 Fig. 4. Both, active and idle times are negative exponential distributed random numbers. The mean active time is $T_{\text{on}} = 10s$, whereas T_{off} is varying to adjust to the different overall traffic of the simulations. The traffic offer is varied within the simulations in order to find and determine the system capacity limits of DCA schemes with the individual improving methods. Applying traffic models for the RNTs in which terminals are sometimes active and sometimes silent, leads to time-varying interference situations and capacity demands where hot spot areas randomly occur on arbitrary locations.

During active phases, the connection is characterized by independent Poisson arrivals of cells, indicated in Fig. 4.

Each connection is defined to use a certain amount of the maximum available capacity of one frequency. While the RNT traffic model is in state "active", cells are generated with a *Mean Cell Rate (MCR)* of 5 % which is uniformly distributed between 4 and 6 %. That means that during the active periods the cell rate will be

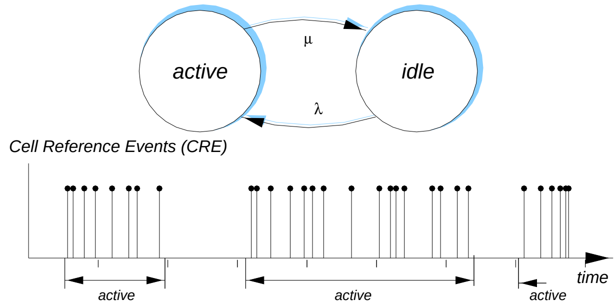

Figure 4: Traffic model for one RNT

in the range of 1400...2100 cells/s.

If the downlink to uplink ratio is 1:1, all RNTs are assigned to the same mean idle time T_{off}. However, for the generation of an asymmetric traffic different idle times can be chosen. The overall traffic offer for one RBS operating in a single frequency band can be expressed as

$$\lambda_{\text{ABR}}(\text{RBS}) = \sum_{i=1}^{\text{No. of RNTs}} \frac{T_{\text{on},i}}{T_{\text{on},i} + T_{\text{off},i}} \cdot \text{MCR}_i \,, \qquad (2)$$

where all parameters $T_{\text{on},i}$, $T_{\text{off},i}$ and MCR_i can individually be adjusted for each RNT.

III. BASIC DCA INVESTIGATION

The channel allocation technique of the simulations is based on the DSA++ protocol developed by ComNets [8]. The entire bandwidth is divided into four frequency subbands. Each of them is divided into 21 traffic containers, which are able to carry a certain number of slots. Applying QPSK modulation with a spectrum efficiency of 2 bit/s/Hz, five slots of 28.6 μs duration can be put into one container. However, the duration of a slot can be adjusted to acknowledge the effect of the modulation schemes as exemplarily shown for QPSK and 16 QAM in Fig. 5. Here, we assume a spectrum efficiency for 16 QAM twice as much as QPSK offers.

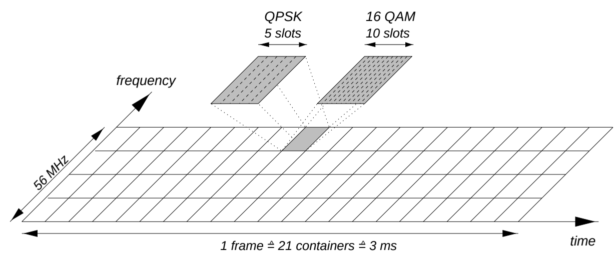

Figure 5: Container principle of the DCA scheme

The reservation and allocation of a container is performed by the RBS. The RBS measures the SINR level of the container it wants to employ. If the SINR level is above a noise threshold value, the RBS perceives the container to be already in use by other RBSs and due to this heavily interfered. Hence, an alternative container is searched for. The noise threshold of -87 dBm was selected after initial simulations with the system's radio parameters.

A tolerable PER of each container defines the criterion when transmission might become too worse to be held on this container.

Table 1: Transmission characteristics of DCA

Offered Traffic per RBS	Rejected calls	Aborted calls	Mean cell delay	Mean number of alloc. containers	Mean container alloc. duration	Mean SINR (DL, UL)	Mean PER (DL, UL)
26 %	0.00 %	0.00 %	1.75 ms	6.48	1.34 s	16.51 dB, 16.07 dB	0.36 %, 0.24 %
28 %	0.00 %	0.02 %	1.68 ms	6.93	0.92 s	16.25 dB, 15.78 dB	0.55 %, 0.36 %
30 %	0.00 %	0.06 %	1.61 ms	7.43	0.62 s	15.90 dB, 15.54 dB	0.82 %, 0.55 %
32 %	0.01 %	0.31 %	1.54 ms	7.83	0.39 s	15.50 dB, 15.18 dB	1.32 %, 0.86 %
34 %	0.02 %	0.77 %	1.48 ms	8.27	0.26 s	15.26 dB, 14.95 dB	1.80 %, 1.42 %
36 %	0.01 %	2.04 %	1.43 ms	8.59	0.17 s	14.98 dB, 14.54 dB	2.56 %, 2.09 %

The tolerable PER is set at 5 %. If this value is surpassed, the RBS tries to perform an intra-cell handover and allocate a new container for a safer transmission. If a container replacement cannot be found and therefore it is not enough capacity available for providing the current connections, a connection will be dropped. The connection with the cuurrently highest PER is chosen for this.

To determine the quality of DCA in FWAN, measurements of the system behaviour and the *Grade Of Service (GoS)* with respect to blocked and dropped MAC connections are assessed. In addition, the PER, cell transfer delays and when appropriate the SINR ratios are evaluated. At each terminal individual carrier and interference values are measured leading to a particular packet loss ratio. The loss ratio depends on the error characteristics, system interference level, and the applied transmission and coding techniques, in other words, on the characteristics of the physical layer.

A. Simple DCA Scheme

These primary DCA simulations were carried out using the DCA scheme parameters explained before. With a traffic load of 26 % per RBS all connections were admitted into the system and all data packets were carried with low transmission errors. Increasing the traffic load leads to a degradation of the system quality as defined by the number of rejected and aborted calls, the SINR, and the PER statistics given in Tab. 1.

The effect that there are more aborted calls than rejected calls can be explained by the way of parameterizing the DCA technique. A connection will only be rejected if the interference level measured on the free container is above the threshold value. If a connection is established it can happen that the quality of the container 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 container, dropping at least one connection if the search fails. The dropped container is returned into the pool of free resources, with the possibility that it might be allocated for the next connection, with the same result. In other words, a container seems to be available for an incoming connection, but after measuring the poor quality there will be no capacity to choose a replacement. Either the variation of the interference threshold value for defining containers in use or changes of the tolerable PER level effect the way the DCA behaves.

The properties of the DCA scheme with varying traffic load are shown in the figures below. Obviously, the number of allocated containers increases if more traffic has to be carried. This effect is seen in Fig. 6. But the duration of a container being allocated does not increase. From Fig. 7 it is seen that the higher the offered traffic the shorter are the allocation periods which is an effect of several reallocations in the system due to the increased interference.

Accordingly, the SINR level decreases with increasing traffic (see Fig. 10). 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.

B. DCA with ARQ

To avoid too many erroneous transmissions an *Automatic Repeat reQuest (ARQ)* protocol can be switched on which was simulated additionally. The ARQ protocol can improve the PER at the cost of increasing the cell delay [2]. Assuming that retransmissions are required by the ARQ, this will increase the transfer delay of the respective cell, which is then re-inserted in the queue. A comparison of the cell delay statistics of a DCA with and without ARQ can be seen from Fig. 8 and Fig. 9.

The longer cell delays can result in situations which might be intolerable for real-time service classes like CBR which have stringent values for the maximum tolerable cell delay. There is a notable difference between the cell delays of the previous simulations and the ones with ARQ. The simple DCA scheme has a mean cell delay of approximately 1.6 ms which even decreases for higher traffics due to the easier scheduling. The DCA scheme with an ARQ protocol has a mean cell delay of 1.8…3.7 ms. Fig. 9 shows the juxtaposition of the cell delays for the simulated traffic loads. 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 be carried with an acceptable quality slightly decreases (compare Fig. 14).

C. 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 an asymmetric traffic distribution than for a symmetric distribution, whereby the traffic offer is the same for both cases. The traffic is determined by a T_{on} time and a certain MCR value equal for up- and downlink, and a variable T_{off} time. To adjust an asymmetric load of, for example, 1:4 for uplink to downlink, where there is an equal number of 24 terminals operating on the uplink and the downlink, the asymmetry condition following Eq. (2) is

$$\frac{1}{4} = \frac{T_{\mathrm{on}} + T_{\mathrm{off,DL}}}{T_{\mathrm{on}} + T_{\mathrm{off,UL}}} \,. \tag{3}$$

Thus for the downlink the mean $T_{\mathrm{off,DL}}$ can be determined indirectly from

$$\lambda_{\mathrm{ABR}}(\mathrm{RBS}) = 30 \cdot \frac{T_{\mathrm{on}}}{T_{\mathrm{on}} + T_{\mathrm{off,DL}}} \cdot \mathrm{MCR} \tag{4}$$

and similarly $T_{\mathrm{off,UL}}$ for the uplink from

$$\lambda_{\mathrm{ABR}}(\mathrm{RBS}) = 120 \cdot \frac{T_{\mathrm{on}}}{T_{\mathrm{on}} + T_{\mathrm{off,UL}}} \cdot \mathrm{MCR} \,. \tag{5}$$

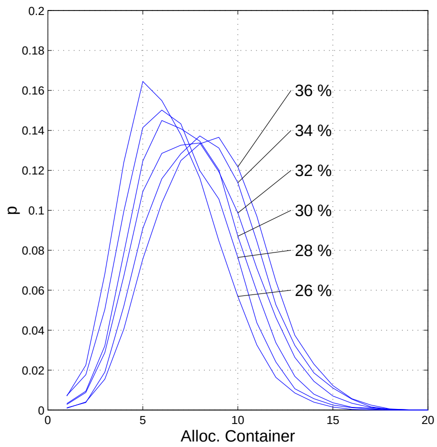

Figure 6: Number of allocated containers

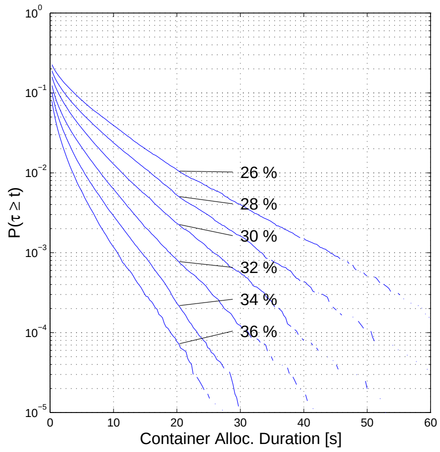

Figure 7: Duration of allocated containers

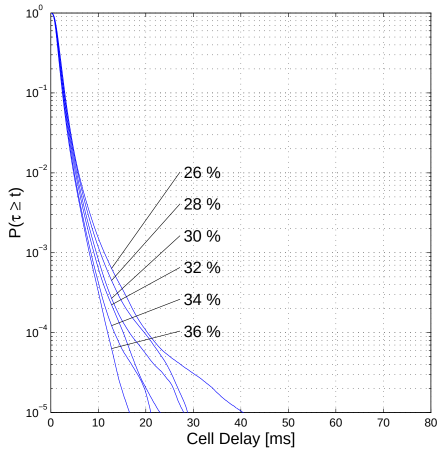

Figure 8: Cell delay for simple DCA

The values can be interpreted such that in this traffic model either 30 terminals with a high traffic load or 120 terminals with a low traffic load create the same capacity at an RBS as the 48 terminals before operating at a medium traffic load. As only 24 terminals of each type are considered the resulting traffic becomes comparable. Simulation results are presented in Section VI.

IV. POWER CONTROL

For FWAN, it will be suitable to apply *Power Control (PC)* to the RBS and RNT transmitters. Connections to RNT's locations close to the RBS can work with significantly lower signal powers and reducing the transmit power for these links will reduce the overall system interference. The simulations will consider PC depending on the estimated path loss value of the link between the RNTs and their belonging RBS. Hence, the transmission power is individually reduced following

$$P_{\text{Tx(PC)}} = \min\left\{P_{\text{max}}, P_{\text{req}} + L_{\text{PL}}(d = d_{\text{Link}})\right\} \;, \qquad (6)$$

where P_{max} is the maximum transmitting power, P_{req} is a required target receive power, here set to -78 dBm, $L_{\text{PL}}(d = d_{\text{Link}})$ is the path loss value of the respective link, and $P_{\text{Tx(PC)}}$ shall be the transmitting power with PC applied. As a result all the received signals have the same power level at the receiver as long as P_{max} (71 dBm) offers the required transmission power.

The intention behind PC 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 send at the same power. Applying PC, the transmission 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. A primitive method is the adaption of the transmission power during installation of the system. The adaption is calculated on the basis of the path loss model. A more sophisticated PC method can be accomplished by regulating the transmission power of each transmitting station according to the current SINR level of its respective connection. For the DCA-PC simulation the simpler method was used. Considering the stationary nature of the RNTs in a FWAN scenario, this strategy seems to be appropriate.

Fig. 11 shows the SINR curves for the downlink from the RBS to its associated RNT at different traffic loads. Once again it can be seen that increasing the capacity required at the RBS, the SINR decreases. The employment of PC can be seen in the progression of the curve for an RBS traffic offer of 26 %. The highest possible SINR in the system is 16.5 dB. This value can be explained by the following argument. The required received transmission of each RNT at its serving RBS is set at -78 dBm. Considering a background noise level of -97.5 dBm and an additional fading margin of 3 dB exactly this SINR 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 Tab. 1 this maximum SINR 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 significantly reduced. Comparing the PER for the DCA scheme with the power-controlled DCA 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 it can be seen in Fig. 12, the PER is almost constant over the distance of an RNT from its RBS. This observation is conform to the purpose of the PC technology. Furthermore, the PER increases for the RNTs located at a distance of more than 1.8 km apart from the RBS. For these terminals the required transmitting power is above its maximum value so that their received power strength is below the predetermined level of -78 dBm. As a result these RNTs have a lower SINR 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 more transmission errors. An imbalance between the PER for the downlink when compared to the uplink is also shown. 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 containers which are suitable for itself. However, while transmitting on the downlink the RBS selects containers which may not be optimal from the point of view of the RNTs. Hence, the PER is increased for the downlink case.

To avoid the increased PER for the more distant RNTs, additional simulations with new PC parameters have been carried out. The path loss value for terminals in a distance of 1.8 km is about

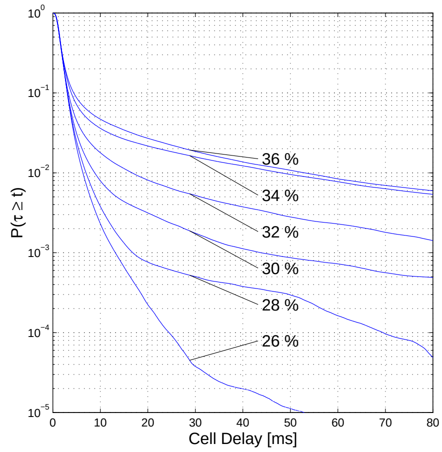

Figure 9: Cell delay with ARQ applied

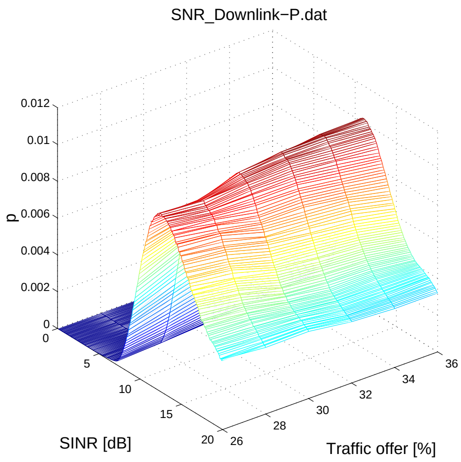

Figure 10: SINR for simple DCA

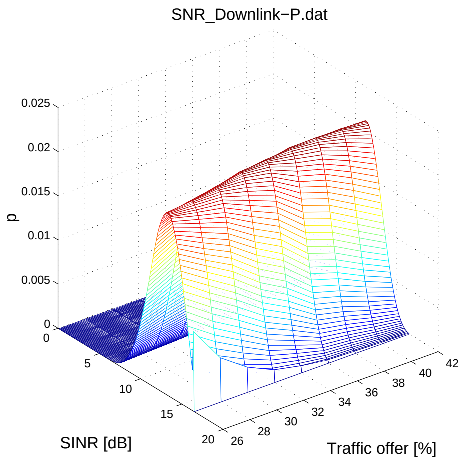

Figure 11: SINR with PC applied

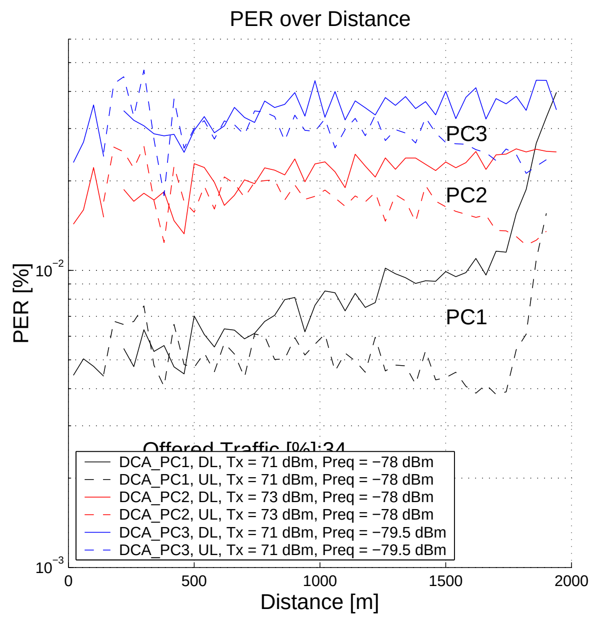

Figure 12: PER over RBS↔RNT distance

149.4 dB which is approximately 1.3 dB less than the maximum path loss value. This was considered in the new simulations.

In a first attempt, the maximum possible transmit power of the stations has been increased by 2 dB to 73 dBm. This results in a more constant PER distribution over the link distance, but with a higher mean PER (PC 2 in Fig. 12).

Another investigation focus on the decrease of the desired receive power level (PC 3). This has been set to -79.5 dBm which is 1.5 dB below the value of the initial PC simulations. The effect is again a more equal distributed PER over the distance between RNT and RBS. However, the overall mean PER is again higher, even compared to the simulation with the increased possible transmit power. Due to the reduced received power requirement the mean link SINR has been decreased and by that the PER for all connections in the systems has become worse.

V. DIRECTIONAL ANTENNAS

The FWAN fixed-to-fixed radio link allows to install high-gain directional antennas at the user's houses as well as sectorized antennas at the base stations. This can improve signal and reduce interference. This section introduces relevant parameters for the consideration of antenna beam forming in FWAN channel modeling and shows the significant improvement in system performance.

Due to the use of directional 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 of

$$L_{\text{Ant}} = \begin{cases} L_0 & |\alpha| \le \delta_0 \\ L_1 & \delta_0 < |\alpha| \le \delta_1 \\ \vdots & \vdots \\ L_s & \delta_{s-1} < |\alpha| \le \delta_s \end{cases}, \qquad (7)$$

at an RNT antenna with beamwidth $\delta = 2\delta_0$, where the antenna pattern is divided into s zones of different loss values.

Herein, α is the angle between the *Line of Sight (LoS)* path, which will be the antenna beam justification, and the direct link

i	δ_i [°]	L_i [dB]
0	3	0
1	5	5
2	10	10
3	20	20
4	180	40

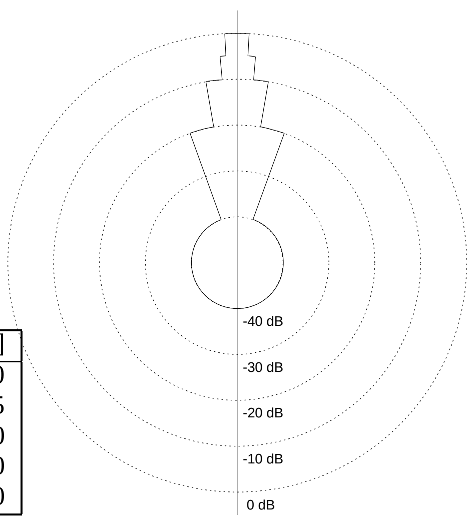

Figure 13: Antenna characteristic

line to another terminal. $L_0 = 0\,\mathrm{dB}$ should be convenient, since the antenna gains G_{RNT} (or G_{RBS}) of the link participating stations are already included in the path loss formula, and the s values for L_i and δ_i, respectively, should consider the beam form of the RNT antenna as depicted in Fig. 13. Note, that for increasing s the modeling of the RNT antenna pattern becomes more detailed as the value of s defines the number of degree intervals within the antenna pattern associated with different losses L_i ($i = 1, \ldots, s$).

For exact simulations the number and positions 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 antenna beam 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 terminal's associated RBS.

So, two additional terms should be included in the formula for propagation path loss referring to a path between two stations by writing Eq. (1) like

$$L_{\mathrm{PL}}(d) = L_0 + 10n \log(d/d_0) + L_{i,St_1} + L_{i,St_2}\,, \qquad (8)$$

where the terms $L_{i,St_{1/2}}$ consider the additional loss values from both stations' antennas depending on the geometric settings of the scenario. If a link to an RBS is examined one of the additional values shall consider the antenna characteristics at this side. Sectorization at the RBS side will cause its own correcting value, which is not further considered in this simulation campaign.

The use of narrowbeam antennas leads to a reduction of interference, thereby increasing the SINR in the system. Raising the signal strength should culminate in a higher capacity utilization of the RBS and a reduced PER. The comparison of the SINR value distributions of the DCA in a system with omnidirectional antennas and in an FWAN employing directional antennas show an increase of 6 dB. The DCA simulation referenced here was simulated with a traffic offer of 32 % while the simulation with directional antennas was performed at 42 %. Both systems showed similar performance of rejected and aborted connections at their respective traffic offers.

VI. RESULTS

The improvement due to the application of the discussed methods is evaluated by the *Grade Of Service (GoS)* defined by

$$GoS = \frac{\text{nos. rejected calls} + (10 \times \text{nos. aborted calls})}{\text{total number of calls}}\,. \qquad (9)$$

The number of aborted calls (also known as dropped calls) is weighted with 10 as the occurance of aborted calls 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 %. Fig. 14 gives an overview of all the different FWAN technologies that were simulated and their respective GoS performance.

Interesting is the observation that DCA without a retransmission ARQ protocol performs slightly better than DCA with ARQ applied. This effect is due to the higher interference caused by the retransmissions of the ARQ protocol. Simulations with asymmetric traffic show an advantage of the DCA scheme, as the scheduler's estimation of capacity demand is more accurate if downlink data has to be transmitted. Uplink requests will appear randomly

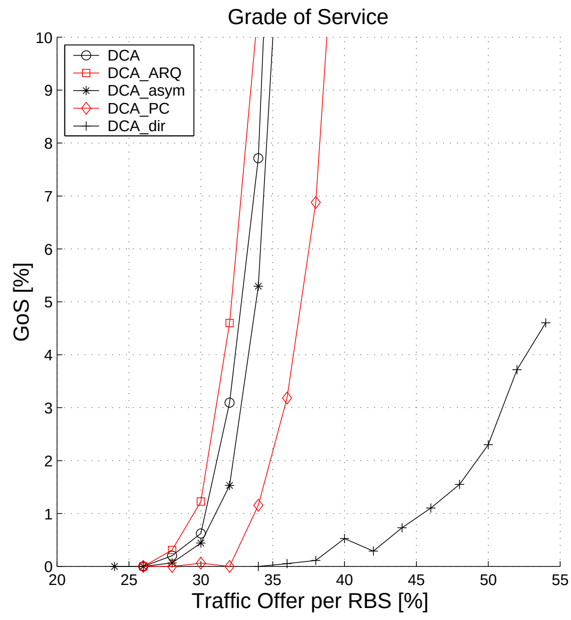

Figure 14: Comparison of GoS

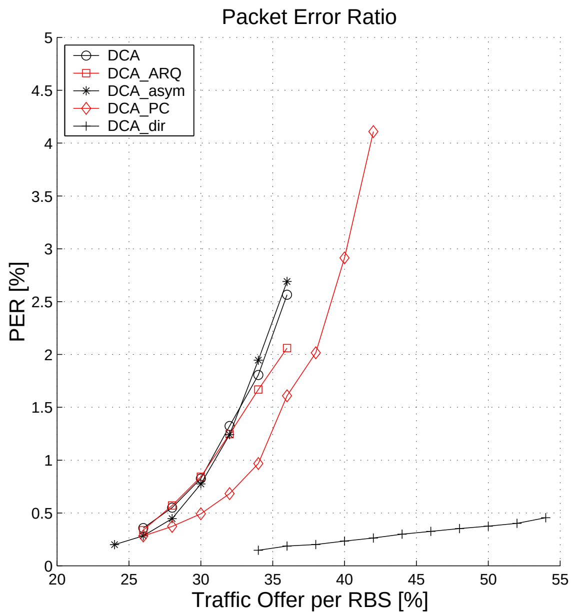

Figure 15: PER of the simulations

and can't neither be predicted nor controlled in a comparable effective way. Hence, we expect a similar gain also for the scenario with PC or directional antennas at the RNT's side.

A considerable raise in capacity is achieved if PC is applied. The power controlled DCA system can carry between 5 % and 6 % more traffic at a comparable GoS. The application of narrowbeam antennas at the RNTs improves traffic carrying capacity by 14 % against the conventional DCA scheme.

The evaluation of the PER of the simulated technologies shows similar results as illustrated in Fig. 15. According to these results, an applied ARQ protocol offers little better performance than the

DCA scheme without retransmission. For the asymmetric traffic scenario a slightly higher PER in cases of high traffic is noticeable. This yields from the higher amount of allocated downlink containers. As the RBS estimates a different interference as present at the RNT, a non-optimal channel allocation may be performed.

Blazing is the gain in sustainable traffic due to interference reduction by PC and directional transmission. In the latter case, the PER stays below 0.5 % even for a traffic offer that occupies 54 % of the RBS's available spectrum.

Comparisons of the enhancing methods can also be made by means of the SINR. It is commonly expected that system performance increases with steadily rising SINR. However, this is not quite correct in the case for the simulated power controlled FWAN. Fig. 16 gives an overview of the mean SINR values plotted against appropriate traffic loads for the different schemes. Here it can be observed that power controlled DCA has a lower mean SINR but as explained before it can carry more traffic than simple DCA. Apparently, the overall interference level in the system also plays a very important role in allocating capacity. Power controlled DCA has a low mean SINR 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. Striking is the extreme increase in SINR through the use of narrow-beam antennas at the RNT station sites, which is a result of the fact that the highly directional antennas emit only 2. . . 3 % of the power compared to an omni-directional antenna. Therefore, although the average transmission power on the link is similar for all schemes, the mitigation of interference is by far the highest in the scenarios with high gain antennas.

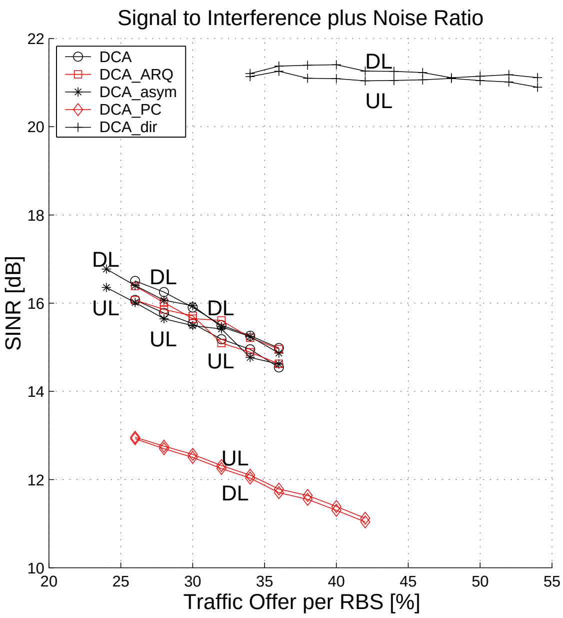

Figure 16: Mean SINR values

VII. CONCLUSION

The possibilities of increasing the performance by applying transmission technologies suitable for the point-to-multipoint FWAN have been proven by computer simulations. This offers network operators to carefully plan their system components in order to achieve the maximum capacity utilization in the broadband network. A powerful DCA algorithm has hereby been implemented in the simulation tool.

Parameters for power settings and the optimal protocol configuration can be derived from the simulation results. Furthermore, the system performance can be predicted, which allows economical calculations for the installation of such an extensive system.

As one result for parameterizing PC it can be stressed that for the whole system it might be reasonable to accept some worse links to the edge of each cell in order to reduce overall interference. Both, an increased transmit power at the long distance RNTs or a reduced required receive power level, lead to a higher PER level on all links.

Similar methods of computer simulations of telecommunication systems will further support manufactures on the fast track of implementing the latest developments in a research area which seems to have the best chances to take off in the age of communication.

VIII. ACKNOWLEDGEMENT

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BIOGRAPHY

Ingo Forkel received the diploma in electrical engineering from the RWTH Aachen, Germany, in 1999. Currently, he is working towards his Ph.D. degree at ComNets, RWTH Aachen in the area of UMTS mobile networks. His research interests include DCA in UTRA, FWAN, localization, and channel and traffic modeling for wired and wireless networks.