Adaptation of Terminal to Base Station Assignment to Terminal Activities and Rain Event in Broadband Fixed Wireless Access Systems

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Abstract— **In point-multipoint systems the signal to interference plus noise ratio highly depends on the assignment of terminal stations (TS) to base stations (BS). The Broadband Fixed Wireless Access (BFWA) systems operate at high carrier frequencies, i.e. microwave domain. In this frequency range wave propagation is highly influenced by precipitation, especially rain. Applying site diversity can mitigate rain attenuation effects, when downlink signal level decreases below a threshold, terminal station can be assigned to an other base station, though in point-multipoint systems this base station re-assignment can raise uplink interferences at other terminals. Present contribution provides a special diversity method which adopts genetic algorithm to dynamically optimize TS-BS assignments in BFWA service area from interference point of view. Efficiency of applying various objective functions are compared considering different aspects.**

I. Introduction

The Broadband Fixed Wireless Access (BFWA) systems are terrestrial cellular point-multipoint (P-MP) networks, wherein both the terminals and base stations have fixed locations. These systems have a lot of advantages compared to the wired networks. The fast, cheap and most flexible installation must be mentioned. These systems can be deployed in some areas, where the wired solution would be hard to install or it would cause the demolition of the land [1]. BFWA systems can be applied in several areas, there are applicable for providing high speed Internet, transferring high speed multimedia (video, sound) data. They can be used for feeder network of cellular systems (GSM, UMTS or B3G/4G) and they can replace some wired solutions. BFWA was the part of the heterogeneous network vision by the European IST project BROADWAN [2]. The provided broadband services need using of high carrier frequency in the 20-40 GHz band, therefore the most degrading factor in these systems is the rain attenuation that must be consider by the network planning procedure. Rain attenuation affects can be mitigated by different diversity methods. If the communication link between terminal station (TS) and its serving base station (BS) is affected by heavy rain, a possible solution could be to connect the terminal to an another base station. This method can improve the signal to interference plus noise ratio (SINR) condition for the effected TS; however, since terminals do not consider decisions of each other it can lead to SINR degradation in other locations of BFWA serving area. Therefore global optimization of TS-BS assignments is necessary. Moreover the number of active, i.e. currently operating TSs can be also varying in time, because in short term subscribers can switch off or switch on his equipments manually, or in long term a new TS can be installed or existing TS can be removed from the system if new subscription appears or an existing one in discontinued, respectively. If a TS is switched on the reconfiguration of current TS-BS assignments may be necessary due to the changed uplink interference conditions.

Previous work [3] was based on applying our special diversity method which adopts genetic algorithm (GA) to dynamically optimize TS-BS assignments simultaneously considering downlink and uplink SINR values in BFWA service area. Present contribution provides various objective functions, with which different optimization goal can be achieved. In order to introduce the efficiency of GA, computer simulations are accomplished in the 38 GHz frequency band considering terminal activities with a Markov chain model.

The paper is organized as follows: Section II presents the principles of BFWA systems and demonstrates the major problem of system planning, the interference situation. Section III shows the importance of suitable TS-BS assignment and deals with our special site diversity algorithm which adopt GA to simultaneously optimize downlink and uplink SINR values in a BFWA system. Simulation parameters are described and results are presented in Section IV.

II. System Assumptions

The simulated BFWA network model is depicted in Fig. 1. The investigated system contains 9 cells with four 90° sectors operating in the 38 GHz frequency band, sectors are frequency divided in a cell, the A, B, C and D distributed 100 MHz subchannels are signed with different colors. All the channels are assumed to use the same polarization. The BSs are signed with white rectangles in Fig. 1. There are 25 TSs in each sector located in a regular 5 x 5 TS grid applying frequency division duplex (FDD) and time division multiple access (TDMA). TSs are not illustrated in Fig 1.

Because of the high carrier frequency, line-of-sight (LOS) condition is assumed. In both communication direction

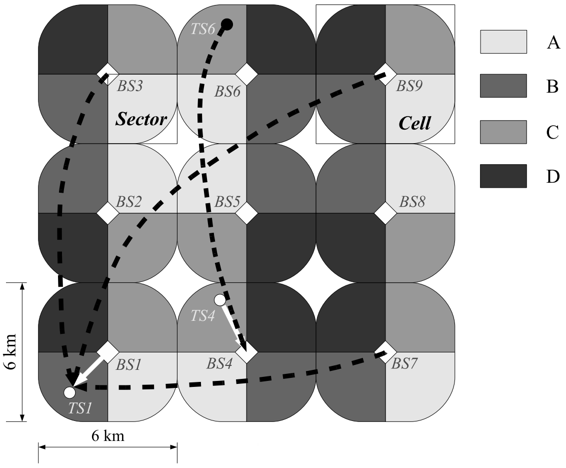

Fig. 1. The simulated BFWA coverage area with dominant interferences

16-QAM modulation is applied by each TS. The TS antenna is sharply directed to the serving BS whereas BS antenna is a 90° sectored antenna. BFWA systems can be fed e.g. fiber optic or satellite. In our investigations ideal fiber optic fed BFWA system is supposed, so degradation of channels, which are feeding base stations, is not taken into account. Alternatively, BFWA can be also fed by satellite links; that is investigated in [3].

The interference situation in up- and downlink are completely different in the BFWA system. The downlink SINR value at a TS (e.g. at TS1 in Fig. 1). The desired signal is sent by the serving BS (signed with BS1), whereas dominant interferer signals are received from other BSs using the same frequency (BS3, BS7, BS9). Uplink SINR at a BS (e.g. at BS4) is mostly the relation of desired signal comes from the own TS (TS4) and the dominant interferer signals come from the other TSs using the same frequency and sending in the same TDMA time slot (TS6). Without fading up- and downlink SINR conditions can be determined from a given network topology (TS and BS locations, applied frequencies and TDMA time slots), however during rain SINR values highly depend on rain attenuation so they are fluctuating dynamically [4].

The rain event was considered with a circularly symmetric Gaussian rain cell profile [3]. The highest rain intensity value is 50 mm/h, whereas the diameter of the rain cell is 3 km. During the simulation this rain cell is moved above the BFWA service area from its left lower corner to its right upper corner in 60 positions. Terminal activities are modeled with a 2-state Markov chain depicted in Fig. 2. States π_0 and π_1 represent switch-off and switch-on states, respectively. A binary time series which describes activity can be generated for every TS before simulation. It comes from the applied $\mathbf{P} = \{p_{ij}\}$ transition probability matrix and the $\mathbf{z} = \{z_i\}$ steady state probability (1), that during the simulation approximately 66 % of terminal stations are switched on in every rain cell position.

$$\mathbf{P} = \begin{bmatrix} 0.9 & 0.1 \\ 0.05 & 0.95 \end{bmatrix}; \mathbf{z} = \begin{bmatrix} 0.33 & 0.66 \end{bmatrix} \qquad (1)$$

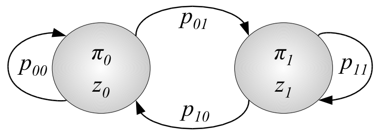

Fig. 2. Markov chain applied for generating TS activities

III. Assignment Base Stations to Terminal Stations

Let us assume that in a BFWA system terminals are able to be assigned to every sector antenna of every base station independently of their locations, moreover a BS can allocate different TDMA slots to the TS. A TS-BS assignment describes to which BS is a given TS assigned and which TDMA slot is used for communication. A TS-BS assignment set describes all of the TS-BS assignments including TDMA slot allocations in the whole service area. Let the **plausible** TS-BS assignment set mean when every TS connects to its closest BS and TDMA slots are allocated e.g. switch on order. The actual TS-BS assignment set affects significantly the evolved SINR values, applying the plausible TS-BS assignment set not definitely the best SINR conditions are achieved on both duplex communication directions (uplink and downlink). Assigning terminals to other base stations applying adaptive smart TS antennas by turning the direction of the main lobe electrically towards to the desired BS or reallocating TDMA slots can improve SINR in the coverage area. In the presence of rain the SINR values are fluctuating dynamically what demands adaptive BS re-assignment as countermeasure to achieve quasi-optimal assignment conditions.

The optimal TS-BS assignment set can be theoretically found with full search algorithm, but its drawback is that every variation of TS-BS assignment sets must be investigated. Depending on the size of the network i.e. on the number of TSs and BSs a huge number of different cases must be investigated. Let N_{TS} and N_{BS} be the number of TSs and BSs, respectively, N_S is number of sectors belong to each BS, whereas N_T is the number of TDMA slots in each sector. The number of possible TS-BS assignment sets is V:

$$V = \frac{(N_{BS} \cdot N_S \cdot N_T)!}{(N_{BS} \cdot N_S \cdot N_T - N_{TS})!} \qquad (2)$$

Apparently there is no point in assigning a TS to a very far BS because of the high path attenuation, so e.g. only the four closest base station antennas can be considered. Anyway the number of variation is exponentially increasing with number of terminal stations, therefore full search is inextricable in real time. Applying GA for optimizing requires much less computation and it should find the optimal TS-BS assignment set.

A. Genetic Algorithm Terminology

Genetic algorithms are widely used stochastic search algorithms to find solution of complex problems [5] [6]. A general GA uses selection, crossover and mutation operations to generate a new population with better fitness than actual population similarly to natural selection and sexual recombination. Generally a population is a set of individual and an individual consists of genes. The so called **elite** individuals are the individuals in a population with best fitness scores. **Parents** are individuals of the actual population whereas **children** are the individuals of the new generated population. In our special case **gene** represents a TS to BS assignment, whereas **individual** represents a given TS-BS assignment set in the BFWA service area [3]. A **population** is a set of individuals, its size denoted with N_I gives the number of contained individuals.

B. Objective Functions

Genetic algorithm maximizes the S fitness score of population which is the maximum of implied indivuals' fitness scores. Fitness score of individual i.e. of a TS-BS assignment set is given by the objective function. In other words optimal TS-BS assignment set has the highest fitness score. As a matter of course applying different objective functions different and different TS-BS assignment set is optimal. Let s_i denote the elementary score value of i^{th} terminal, which is calculated using an $f(.)$ function of $SINR_i^{(DL)}$ downlink and $SINR_i^{(UL)}$ uplink SINR values:

$$s_i = w_i^{(DL)} \cdot f\left(SINR_i^{(DL)}\right) + w_i^{(UL)} \cdot f\left(SINR_i^{(UL)}\right) \quad (3)$$

In (3) $f(.)$ depends on the applied average objective function, SINR values are in dB, the w_i weighting factors can be different for uplink and downlink and can be different for each TS. These factors describe the importance of the communication direction. Different TS types with different importance factors can be defined depending on their subscribed service. In this paper uplink and downlink direction of communication assumed to be equally reliable for all TSs, i.e. the same importance of downlink and uplink directions is assumed, therefore $w_i^{(DL)} = w_i^{(UL)} = 0.5$.

Two types of objective functions are distinguished in this paper. In case of maximal average (MA) the S fitness score is calculated as average of s_i scores:

$$S = \frac{1}{N_{TS}} \cdot \sum_{i=1}^{N_{TS}} s_i \quad (4)$$

Normal maximum average (N-MA) objective function aims to simultaneously maximize downlink and uplink SINR values. Therefore in this case $f(.)$ is the simple natural logarithm function with input arguments of downlink or uplink SINR values: $f_{N-MA}(SINR_i) = ln(SINR_i)$. However; applied modulation and coding technique determines required down- and uplink SINR ratio for each TS, too high SINR values are unnecessary. Let $SINR_{i,min}$ denote required minimum downlink or uplink SINR value for i^{th} TS satisfying $BER = 10^{-6}$, where BER is the bit error ratio; and let $SINR_{i,opt}$ denote the optimal downlink or uplink SINR value which is 2 dB higher than $SINR_{i,min}$ satisfying $BER < 10^{-10}$; $\Delta SINR_i$ is defined by (5), where $SINR_i$ is the current downlink or uplink SINR for the i^{th} terminal.

$$\Delta SINR_i = SINR_i^{[dB]} - SINR_{i,opt}^{[dB]} \quad (5)$$

Modified improved polynomial maximum average (MIP-MA) objective function aims to avoid unnecessary high SINR values tuning both downlink and uplink SINR values of each TS to the suitable $SINR_{i,opt}$ values. In this case $f(.)$ is defined by a $f_{MIP-MA}(.)$ polynomial function using $\Delta SINR_i$ as input argument:

$$f_{MIP-MA}(\Delta SINR_i) = \begin{cases} -0.01 \cdot (\Delta SINR_i)^2 + 2 & , \Delta SINR_i < 0 \\ 2 & , \Delta SINR_i >= 0 \end{cases} \quad (6)$$

As it can be seen in this case if SINR is higher than its optimal value $f_{MIP-MA}(.)$ is constant. This means that unnecessarily high SINR values are not punished. In other words SINR can be higher than optimal value, but the elementary score of high SINR is the same as the elementary score of optimal SINR.

An other type of objective functions is the MinMax, with which the minimum of s_i elementary scores can be maximized, therefore the S score is calculated with (7), where s_i elementary scores are calculated with (3) considering $f_{MinMax}(.)$ as the same as $f_{N-MA}(.)$.

$$S = \min_i (s_i) \quad (7)$$

C. Genetic Algorithm Operations and Parameters

Our applied GA works in usual way, but complement individuals are also used (GA with complements, GAC) [7]. Main operator functions, such as creation, crossover and mutation, had to be made for our purposes. Let us briefly overview the main GA parameters and operations, the details are presented in [3]. Genetic algorithm operation **creation** provides initial population using the plausible TS-BS assignment set N_I times. Elite individuals are guaranteed to survive to the next generation. Therefore after generating initial population, GA selects the elite individuals (number of N_E), and put them into the new population. Remaining individuals of the new population is generated with **crossover** and **mutation** operations. Operation **crossover** generates N_C pieces of crossover children. Parents of each crossover child are chosen randomly. Half of genes (i.e. TS-BS assignments) are inherited from one of the parents whereas other half of genes are comes from other parent. The N_M number of individuals are created by **mutation** operation, its value equals to $N_I - N_E - N_C$. Mutation randomly selects N_{MG} pieces of TSs (genes) and tries to assign them to another BS. In case neither of BSs have free time slot, mutation fails i.e. TS is not assigned to another BS. After generating derived population, its fitness score must be calculated than convergence criteria must be checked. If criteria is fulfilled the algorithm stops, otherwise it goes on to the next iteration. Possible convergence criteria is if the cumulative change in the populations fitness values over K_t fitness tolerance interval is less than σ_S fitness tolerance [3].

IV. Simulation parameters and results

In this work different TS-BS assignment methods are compared. The simplest is a no-diversity solution: static TS-BS assignment without optimization i.e. the plausible TS-BS assignment set is applied during the whole simulation. Applying the simple site diversity (SD) each TS is assigned to the BS with highest downlink signal level in every rain cell position. Third method is performing GA in every rain cell position to get maximal S fitness score. Different objective functions which are presented in Section III-B are applied. The parameters of GA are: $N_I = 40$, $N_E = 4$, $N_C = 8$, $N_{MG} = 1$, $\sigma_S = 10^{-25}$ and $K_t = 500$.

Depending on the applied objective function genetic algorithm needs various number of iterations to find quasi-optimal TS-BS assignment set. The average of normalized convergence curves are depicted in Fig. 3.

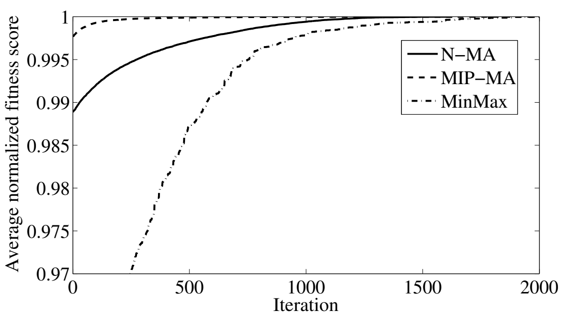

Fig. 3. Average convergence of genetic algorithm using different objective functions

Let N_{100} and N_{90} denote the necessary iteration number to reach 100% and 90% of best fitness score, respectively, they values and the average necessary improvement (Imp. [%]) are summarized in Table I. Please notice that applying MIP-MA objective function GA finds suitable good solution quiet quickly (in N_{90} iterations) and GA had to improve the fitness score in least extent.

TABLE I

Necessary iteration numbers of GA

objective function	N_{100}	N_{90}	Imp. [%]
N-MA	1627	836	1.11
MIP-MA	2299	266	0.23
MinMax	2153	477	14.61

As an example Fig. 4 shows the found quasi-optimal TS-BS assignment set applying adaptive GA with MIP-MA objective function in the 15^{th} rain cell position in the BFWA service area whose schematic representation is depicted in Fig. 1. The dashed and solid lines show the TS-BS connections if TS is re-assigned to a neighboring BS or not, respectively. The black circle denotes the rain cell whereas the solid wide black line shows the rain path. It can be stated that not only TSs under the rain cell are assigned to BS in neighboring cell, but terminals far from the rain cell as well.

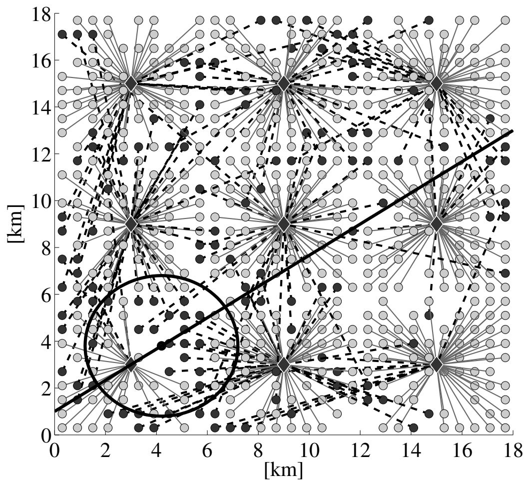

Fig. 4. The found quasi-optimal TS-BS assignment set applying GA with MIP-MA objective function

From the service provider point of view the more interesting quantity of efficiency is the ratio of subscribers with appropriate high downlink and uplink SINR values. Let the time depending downlink and uplink satisfied TS ratio refer to the ratio of terminal stations for which the currently evolved SINR value is higher than $SINR_{i,min}$ in downlink and in uplink direction, respectively. The satisfied TS ratio as the function of rain cell position is shown in Fig. 5-6 applying different TS-BS assignment methods.

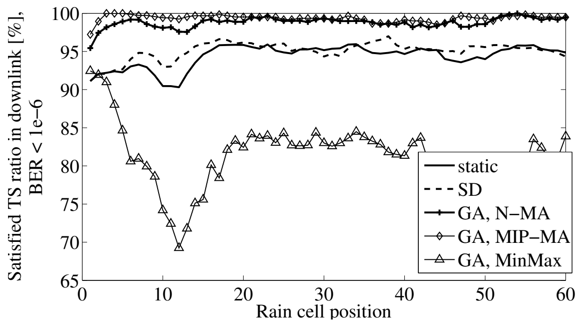

Fig. 5. Satisfied TS ratio as a function of rain cell position in downlink applying different TS-BS assignment methods

These important diagrams shows that GA with MinMax objective function provides the worst satisfied TS ratio around 75-80% both in downlink and uplink and using static TS-BS assignment method only at least the 90-95% of TSs are satisfied both in downlink and uplink direction, which is intolerable for the service provider and using SD only a minor improvement can be achieved. Applying GA with

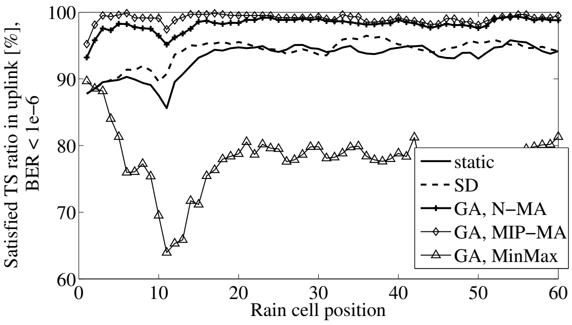

Fig. 6. Satisfied TS ratio as a function of rain cell position in uplink applying different TS-BS assignment methods

N-MA the satisfied TS ratio can be improved dramatically, up to approximately 97-99% and applying MIP-MA objective function the satisfied TS ratio can be a bit more improved in both communication directions. On the other hand too high SINR values are unnecessary. Let the time depending ratio of TSs with unnecessarily high SINR in downlink and uplink (UHR) refer to the ratio of terminal stations for which the currently evolved SINR value is higher than or equals to $SINR_{opt} + 5dB$ in downlink and in uplink direction, respectively. The UHR as the function of rain cell position is shown in Fig. 7-8 applying different TS-BS assignment methods.

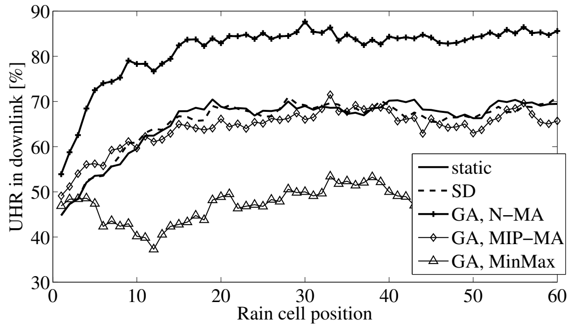

Fig. 7. Ratio of TSs with unnecessarily high SINR as a function of rain cell position in downlink applying different TS-BS assignment methods

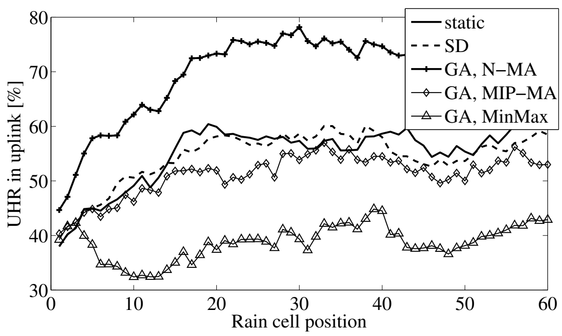

Fig. 8. Ratio of TSs with unnecessarily high SINR as a function of rain cell position in uplink applying different TS-BS assignment methods

In case of applying static or SD methods UHR is around 50%. As expected based on function definitions GA applying N-MA provides highest UHR up to 75-80% in both directions of communication. Using GA with MIP-MA the UHR also around 50%, so ratio of TSs with unnecessarily high SINR are successfully restricted. However; it must be mentioned that GA with MinMax objective function provided the less UHR. To draw a lesson, from both the satisfied TS ratio and UHR point of view the suggested algorithm is when TS-BS assignment is adaptively optimized with genetic algorithm which is using our special MIP-MA objective function.

V. Conclusions

In BFWA systems TS-BS assignment affects SINR conditions, therefore optimization of TS to BS assignment is necessary even if there is no rain event above the network. The optimization can be performed with the presented genetic algorithm simultaneously considering uplink and downlink SINR. Precipitation causes SINR degradation, which can be mitigated with applying site diversity. Different diversity algorithms were compared in a BFWA system. A special site diversity which adopts genetic algorithm is presented which is able to use different objective functions. Effectiveness of various objective functions are compared. A proposal was given to apply a feasible algorithm in BFWA systems with which the average joint downlink and uplink SINR conditions and thus the downlink and uplink TS satisfaction can be remarkably improved compared to the case of applying simple site diversity. Applied modulation and coding technique determines required SINR ratio for communication, too high SINR values are unnecessary. Using this suggested algorithm the occurrence of unnecessary high SINR values can be mitigated in the system.

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