Evolutionary Approach for Efficient Resource Allocation in Multi-User OFDM Systems

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Abstract – **Orthogonal Frequency Division Multiplexing is a promising technology for high data rate transmission in wideband wireless systems for achieving high downlink capabilities in the future cellular systems. To minimize the overall transmit power, the genetic algorithm approach was proposed for adaptive subcarrier and bit allocation based on channel state information. This is done by assigning one subcarrier for one user and each user a set of subcarriers and by determining the number of bits and the transmit power level for each subcarrier. The simulation results show that genetic algorithm approach produces better results compared to conventional algorithms in optimum power allocation. The results further conclude that genetic search helps fast convergence and can handle large allocations of subcarriers to users (many subcarriers to one user) without performance degradation.**

Index Terms:: **adaptive power allocation, Genetic Algorithm, fitness, subcarrier, OFDM, frequency, bit error rate**

I. INTRODUCTION

In recent years, wireless networks have rapidly evolved all around the world. Wireless communications became a vibrant research area in communication field due to increased in use of mobile communication systems and progress in VLSI technology. Continuous research is required to improve the performance, type of usage, adaptability of traffic conditions, prioritization schemes, effect of hand-offs, reliability of connectivity, avoid unpredictable situations, and appropriate cost effects for normal user.

Due to increase in cellular users in recent years, the uninterrupted and reliable communication facility is in demand. To meet the increased demand, appropriate frequency spectrum must be allocated. Currently the spectrum availability for this usage is limited. Consequently, efficient use of channel frequencies becomes more and more significant. Based on service requirements, the allocated spectrum is divided into a number of channels. To meet the current user demand, the channels must be assigned and reused to maximize the throughput with minimum interference. Many channel allocation and bit transfer techniques came into existence to meet the current demands.

Orthogonal Frequency Division Multiplexing (OFDM) is a promising technique for next generation of wireless communication systems. OFDM divides the available bandwidth into N orthogonal subchannels [8, 9 15]. By adding a cyclic prefix (CP) to each OFDM symbol, the channel appears to be circular if the CP length is longer than the channel length. Each subchannel thus can have modeled as a time-varying gain plus Additive White Gaussian Noise (AWGN). Adaptive modulation can greatly improve the system spectral efficiency by changing its modulation constellation and transmit power according to the instantaneous Channel State Information (CSI). In the frequency selective fading channel, the combination of OFDM and adaptive modulation can utilize the metrics of both technologies and is attracting more and more interests.

The flexibility of channel management in OFDM systems provides an attractive multiple access control mechanism in multi-user environment. Multi-user OFDM adds multiple accesses to OFDM by allowing multiple users to share the subcarriers in each OFDM block. Allocation of the channel (subcarrier) with best channel-to-noise ratio improves the performance of the system. The system performance can be further enhanced by employing resource allocation techniques including bit and power allocation for each channel in the flexibility of channel management in OFDM systems provides an attractive multiple access control mechanism in multi-user environment. Multi-user OFDM adds multiple accesses to OFDM by allowing multiple users to share the subcarriers in each OFDM block. Allocation of the channel (subcarrier) with best channel-to-noise ratio improves the performance of the system. The system performance can be further enhanced by employing resource allocation techniques including bit and power

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allocation for each channel in response to the channel state information. In fact, multi-user OFDM is superior to fixed allocation schemes such as frequency division multiple access (FDMA) and time division multiple access (TDMA) and a promising technology for future communication systems.

The greedy algorithm (adaptive bit allocation algorithm) for single user OFDM system gives an optimal solution to minimize the overall bit power allocation [1, 2-5, 10, 18-24]. The greedy algorithm may not be suitable in a multiuser environment because a subcarrier for one user will be best but not for other user or users. An optimum solution using greedy algorithm may be possible when the overall subcarriers are allocated to users by adaptive subcarrier allocation in the OFDM systems [19]. Rohling et al. [14] presented a simple greedy algorithm, and showed that it performs better than simple banded OFDM Access. Wahlqvist et al. [17] showed that dynamic resource allocation can improve quality of service (QoS).

The optimum solution for subcarrier and bit allocation can be categorized as static and dynamic allocation. The static subcarrier allocation uses fixed resource allocation schemes namely Time-Division Multiple Access (TDMA) and Frequency-Division Multiple Access (FDMA). In these schemes, the channel conditions are ignored and each user is allocated a predetermined time slot or frequency band to apply OFDM system with Amplitude Modulation (AM). Wong et al. [21] proposed iterative searching algorithm that applies Lagrangian relaxation for optimum multiuser subcarrier, bit, and power allocation. The algorithm is close to the lower bound with requirement of high and complex computation. Ehsan's [2] algorithm over-simplifies the subcarrier allocation but could not fully utilize the multiuser diversity. Zhang [24] proposed water-filling algorithm (transmit more signal power in the better channels and less signal power in the poorer channels) similar to Wong's [21, 22] algorithm to avoid computational complexity.

In this research, we used a simple genetic algorithm [6, 7, 11, 12, 16] implemented in MATLAB language. The genetic algorithm was used for two cases: each user is allocated one subcarrier; and each user is allocated more than one subcarriers according to the user demand. Section 2 formulates the problem of dynamic resource allocation of resources in multiuser OFDM system and describes the system model of multiuser OFDM system. The genetic algorithm based description for this problem and parameters for genetic based system are discussed in Section 3. Numerical results are obtained and discussed in Section 4. Finally, conclusions are drawn in Section 5.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Let an OFDM system have K (k = 1, 2, . . , K) users and N (n = 1, 2 . ., N) subcarriers. The system assigns a subset of N subcarriers to a user and determines the number of bits/symbol per each assigned subcarrier on downlink transmission.

Let $C_{k,n} \in$ {0, 1, 2 . . ., M} denote the number of bits of the n^th subcarrier, which is assigned to the k^th user. R_k is the number of bits that need to be transmitted in an OFDM symbol. M is the maximum number of information bits per symbol that can be transmitted by each subcarrier. The parameter $C_{k,n}$ determines the adaptive modulation mode (BPSK, 16 QAM, or 64 QAM) for transmission for each carrier.

Let $\alpha_{k,n}$ denote the channel gains over all N subcarriers for the kth user. The required transmission power for the specified bit error rate (BER) at $C_{k,n}$ bits per symbol is given by [17]

$$p_{k,n} = \frac{f_k(c_{k,n})}{\alpha_{k,n}^2} \quad \text{-----------------} \ (1)$$

For the multiuser OFDM systems under consideration, we do not allow more than one user to share a subcarrier. To formulate the allocation problem, we define

$$\rho_{k,n} = \begin{cases} 1 & if \quad c_{k,n} \neq 0 \\ 0 & if \quad c_{k,n} = 0 \end{cases} \quad \text{----------} \quad (2)$$

Variable $\rho_{k,n}$ is either 1 or 0, and the sum of all $\rho_{k,n}$ is equal to 1 for any particular n. This implies that only one user can employ the nth subcarrier. The required total transmission power $(P^*_{k,n})$ can be written as

$$P^*_{k,n} = \sum_{n=1}^{N}\sum_{k=1}^{K} \frac{f_k(c_{k,n})}{\alpha_{k,n}^2} \times \rho_{k,n} \quad \text{------------} \ (3)$$

The subcarrier, bit and power allocation problem for minimizing the total transmission power the equation (3) can be formulated as:

$$\min_{c_{k,n}, \rho_{k,n}} \sum_{n=1}^{N}\sum_{k=1}^{K} \frac{f_k(c_{k,n})}{\alpha_{k,n}^2} \times \rho_{k,n} \quad \text{-----------} \ (4)$$

subject to

$$\sum_{k=1}^{K} \rho_{k,n} = 1, \ \text{for} \ n = 1,\ldots,N \quad \text{----------} \ (5)$$

$$\sum_{n=1}^{N}\sum_{k=1}^{K} \rho_{k,n} = N \quad \text{for n= 1 . . N} \quad \text{--------} \ (6)$$

and $c_{k,n}$ Є {0, 1, 2, . . , M}

$$R_k = \sum_{n=1}^{N} \alpha_{k,n} \quad \text{for k = 1,…, K} \quad \text{----------} \ (7)$$

and the required power for supporting c bits/symbol at a given BER (bit error rate) [13] is

$$f(c_{k,n}) = \frac{N_0}{3}[Q^{-1}(\frac{BER_n}{4})]^2.(2^r - 1) \quad \text{------------} \ (8)$$

where

$$Q(x) = \frac{1}{\sqrt{2\Pi}} \int_x^{\infty} e^{-t^2/2} dt \qquad \text{------------- (9)}$$

and

$f_k(c_{k,n})$ is convex and increasing in c and that f(0) = 0, means no bits transferred.

For a given BER, using the normalized channel gain and the number of bits per symbol, we can calculate the minimum power required to transfer the symbol over a given subcarrier. The signal to noise ratio (SNR) is calculated as [26]

$$SNR = \frac{average - signal - power}{average - noise - power}$$

Algorithm 1

1. Calculate the SNR for all users, assign appropriate bits to transfer basing on the channel to threshold ratio (if the channel gain is less than minimum threshold assign 0 bits to transfer)
2. Assign the n^{th} subcarrier to user k as user demands arrive and find minimum SNR of the subcarriers allocated to each user.
3. For each user check that every subcarrier allocated to that user, has a SNR greater than a minimum (lower bound) threshold.
4. Perform the allocation of subcarriers to users in the order of lowest mean SNR to highest mean SNR. If all subcarriers meet the minimum SNR threshold, then the user allocation is complete
5. Redistribute the remaining subcarriers by allocating them to users that have an SNR significantly greater than the minimum SNR threshold. Repeat step 4 till all the subcarriers are allocated.

III. GENETIC ALGORITHM BASED ALLOCATION

Genetic Algorithms (GAs) [6, 7, 12, 16] provide learning method motivated by an analogy to biological evolution. Rather than search from general-to-specific hypotheses, or simple-to-complex, GAs generate successor hypotheses by repeatedly mutating (mutation is a genetic operator used to maintain genetic diversity from one generation of a population of chromosomes to the next) and recombining parts of the best currently known hypotheses. At each step, a collection of hypotheses called the 'current population' is updated by replacing the fraction of population by offspring of the most-fit current hypotheses. The process forms a generate-and-test beam-search of hypotheses, in which variants of the best current hypotheses are most likely to be considered next. The genetic algorithms applications are inspired by many factors:

- A successful and robust method for adoption within biological systems.
- Can search spaces of hypotheses containing complex interacting parts, where the impact of each part on overall hypothesis fitness may be difficult to model.
- Easily parallelized and can take the advantage of the decreasing costs of powerful computer hardware.

The subcarrier allocation problem to multiple users has many different permutations, thereby making the solution space very large and a suboptimal allocation of subcarriers to users is acceptable. The GAs are more suitable where the solution space is very large and a suboptimal solution may be sufficient in many scenarios. The problem addressed by GAs is to search the space of candidate hypotheses to identify the best hypotheses identified by a fitness function. The typical GA operates by iteratively updating a pool of hypotheses, called a population. During each iteration, the members of the population are evaluated according to the fitness function. A new population is then generated by probabilistically selecting the most-fit individuals from the current population which is forwarded to next generation population. The iterative improvement generally leads to near optimal solutions. The above discussion shows that GAs are suitable for the optimization of the subcarrier and bit allocation problem in a multiuser OFDM system.

The optimization problem to be solved by GAs is given in Equation 4. The processing steps in GA based algorithm are as follows:

1. **Generate chromosome of N elements** (maximum size of the chromosome is assumed as 128) and total number of chromosomes (population) as 30 for the experiment. Each element in the chromosome is a subcarrier allocated to a user (one user may be allocated more than one subcarrier). Thus the population is a 2-D array, where the rows represent chromosome number and column of a row represents subcarriers.
2. **Evaluate-** use the water-filling method used by Wong [21] or Algorithm 1 (see section 2) to allocate each user's bits and subcarrier and calculate the overall transmission power as fitness of each chromosome. The higher fitness is the smaller value of the power.
3. **Generate** the new population using crossover and mutation (see Appendix A) probability.
4. **Repeat** step 2 and step 3 till the system converges.

In this paper, we calculated each user's power requirement and the total transmission power required by all users. The subcarriers allocated as per the user's request arrives. The fitness is equal to the power required for all users or required by all subcarriers allocated to users. The lower the value of power $P^*_{k,n}$ is the higher fitness.

The genetic algorithms had built-in selection of stronger individuals to be the winners from the old generation to new generation. Each chromosome had the format shown in Fig 1. The value of each element in the array (chromosome) is confined to a user signal and randomly generated. The array represents a solution to the optimization problem.

Chromosome element -1	Chromosome element -2	------	Chromosome element n
Subcarrier 1	Subcarrier 2	-----	Subcarrier n

Fig. 1 Coding of Genetic Algorithm

For the optimization of our subcarrier and bit allocation problem, the final optimal allocation is sure to have the following features:

- Equation (1) shows that the power gain $P_{k,n}$ can be achieved by channel gain $\alpha_{k,n}$ (larger the channel gain lower the power needed). Therefore, the subscriber with largest channel gain will find the lowest transmission power as in equation (4).
- From equation (7), the number of subcarriers that each user needs according to the rate R_k. The channel gain for each user is

$$R_k = \sum_{n=1}^{N} \alpha_{k,n} \quad \text{for } 1 \le k \le K \text{ subject to equation (2)}$$

The number of subcarriers that a user k can take is given by m_k :

$$m_k = \frac{N.R_k}{\sum_{k=1}^{K} R_k} \qquad 1 \le k \le K \text{ when } \sum_{k=1}^{K} m_k \le N$$

Now generate k users so that the total users can take maximum of N subcarriers. Allocate the subcarrier to the user k that has largest channel gain at this subcarrier, i.e. max $\alpha_{k,n}^2$. If total bits allocated for user k is with one subcarrier is c_k, then bits for allocated for user k with n subcarriers is $\{n\} \cup c_k$.

We improved the GA processing by the following steps: (1) Add high fitness chromosome at the end of each generation or while forming the new generation. The searching time was reduced by adding the good genes to the population at the end of each generation because it converges quickly. (2) Vary the chromosome size to choose those sizes which result in faster convergence and generate better solution.

IV. SIMULATION RESULTS

The GA application to bit and power allocation is extensively studied in [27-30]. Initially the chromosome length was fixed minimum 50 elements due to bit rate R=256 [30] by taking maximum bit rate R>6*N (allocation vector takes 6 bits for 64 QAM), where N is maximum number of sub carriers. Using the water filling algorithm (Algorithm 1 in section 3) the subcarriers were allocated as needed. The simulations were done with chromosome length 50, 60, - - - 100. The target bit error rate (BER) is set to 10^{-3}. The bit allocation vector can take 0 bits (no modulation), 2 bits (QPSK), 4 bits (16 QAM), 6 bits (64 QAM). The other parameters are provided below:

- Each element of the chromosome represents a subcarrier (chromosome length 50, 60, 70, 80, 90, and 100)
- One or more subcarriers are assigned to each user.
- The total transmission power is considered instead of one user's transmission power, so the balance among the users is kept.
- Subcarriers allocated according to need (in the present case randomly)
- Population: 30
- Generations: 10 to 200
- Crossover: 0.6
- Mutation: 0.03

The transmit power required by the subcarrier for transmit signals using Algorithm 1 is compared with models FDMA, TDMA, Zhang's [24] algorithm. The comparison results are shown in Fig 2. The results shows that the transmit power required by the current algorithm is much lower than the models FDMA, TDMA, and Zhang's algorithm. As the number of users is increasing, the current algorithm performs close to Zhang's algorithm, but as the number of users increases more than 8, the current algorithm performs better than Zhang's algorithm. But, the transmit power required by Zhang's algorithm and current algorithm is much leach than FDMA and TDMA.

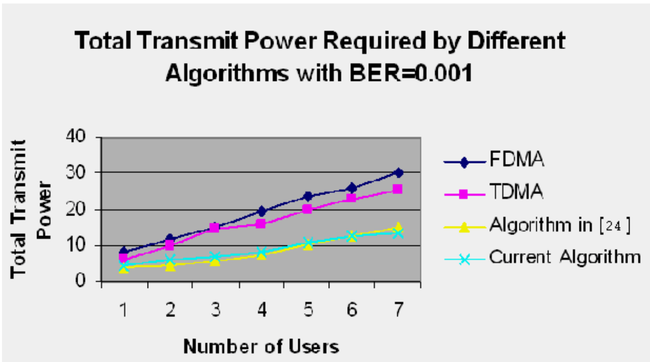

Fig. 2 Transmit Power required by 8 users and 128 channels – Comparison of GA Approach

In the second case, the subcarrier allocation algorithm [25] was used to calculate the power for the population in each generation. The genetic algorithm was executed for 200 generations finding the optimum power requirement. It was observed that the system converges after 60 generations and power required at convergence was below 25 units (see Fig 3). In this experiment we used population size was 30, and chromosome length was 50.

Fig. 4 shows that the algorithm converged after 40 generations. In each case minimum 50 subcarriers are used and the number of users is ≤ number of subcarriers or size of chromosome. Eshan's (see Fig. 2 of reference [2]) iterative and adaptive joint subcarrier and bit allocation algorithm requires 40 units of power with 10 users. In the present case, the Fig. 4 converges after 40 generations and the mean power requirement is less than 20 units with chromosome length are 50.

Wang's [23] experimented with modified simple genetic algorithm. Modification is that a specified percentage of high fitness genes (chromosomes) replaces are added (replaced with low fitness genes) at the end of each generation for faster convergence. Wang's modified GA model with 32 subcarriers converges after 140 generations (see Fig 4d of Wang [2]) with 8 users. The present GA model with 50 subcarriers converges after 40 generations with chromosome length 50 (see Fig 3).

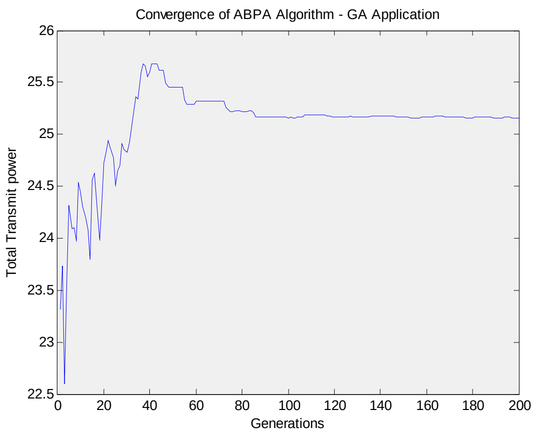

Fig. 3 Convergence of total power with Generations

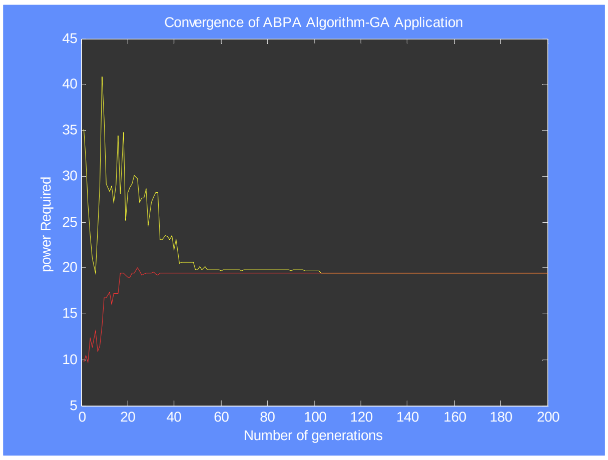

Fig. 4: Convergence of total power required to subcarrier

The results from Fig.3 and Fig. 4 show that the system converges after 40 generations with chromosome length 50. The results show that data transfer is efficient in power requirement with allocation of more subcarriers to users [1, 2, 3]. It is clear from Fig. 5 (with BER= 0.001 and data rate = 256) that optimum power requirement stabilizes as length of chromosome increases. Hence we conclude that chromosome length helps to achieve optimum power requirement. The simulations were tested for BER 0.1 to 0.00001 for adaptive bit power allocation algorithm [25] with GA model. The ratio of BER to SNR (dB) is provided in Fig. 5.

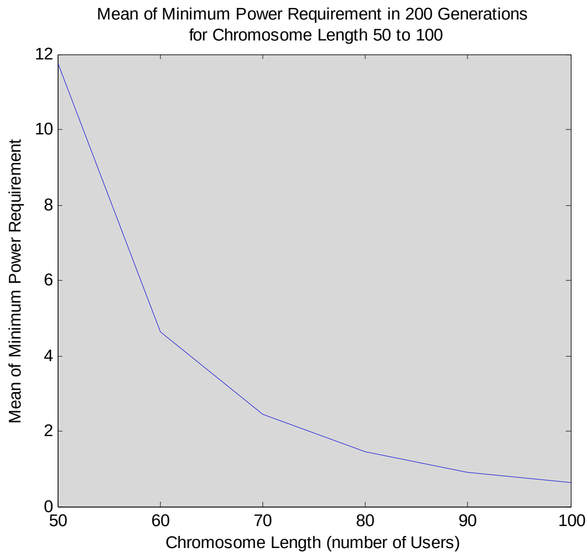

Fig 5: Mean of Minimum Power requirement for various chromosome Lengths

The subcarrier allocation to users using Algorithm 1 and calculating the total transmit power using genetic algorithm is given in Fig. 6. Fig 6 also does the comparative study of four methods. The methods includes: Algorithm 1 and calculate the transmit power, Zhangs algorithm [24], Wang's [23] genetic algorithm results, and genetic algorithm used with Algorithm 1. The simulation results show that GA with Algorithm 1 performs better than all models.

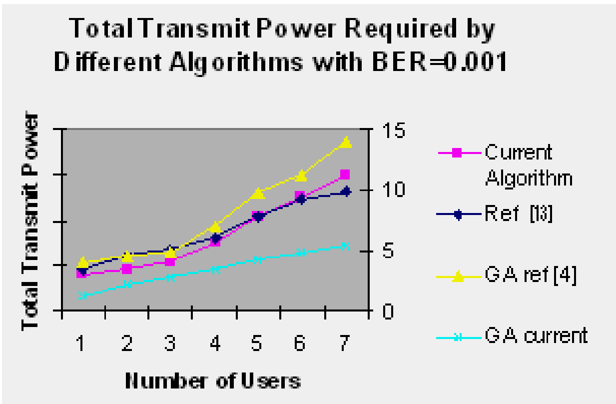

Fig. 6 Transmit Power required by 8 users and 128 channels – Comparison of GA Approach

The numerical results in Fig 7 is the comparison of Gao's [25] conventional algorithm and the proposed GA application. The results in Fig. 7, is the ratio of BER to SNR, conclude that current genetic algorithm application performs better than conventional bit and power allocation algorithm of Gao's [25]. The results in the current research conclude that GA application is better and alternative model compared to existing conventional models [2, 8, 9, 21, 25].

BER →	0.1	0.01	0.001	0.0001	0.00001	
Current GA-Result	4..3510	10.8841	13.0873	14.6478	15.9600	SNR ←
X. Gao's ABPA algorithm	6.7631	13.3803	15.1822	17.5615	18.1615	SNR ←

Fig. 7 Convergence of system with SNR [25]

V. CONCLUSIONS

In this paper, the adaptive bit and power allocation with genetic algorithm application was presented. The paper presents the problem with fixed length of chromosome (one gene equals one subcarrier) and variable length of chromosome (a user was allocated more than one subcarrier using Algorithm 1). The results in the present paper using GA model (see Fig. 3 and Fig. 4) with 50 subcarriers are better than Gao's [25], Ehsan's [2] power allocation algorithm and comparable with Wang's model using GA [23] and converge faster than Wang's method. If the number of subcarriers is increased, the current method performs much better than Wang's GA method [23]. The proposed model was compared with TDMA, FDMA, and Zhang's algorithm [24] (see Fig 2) and proposed adaptive allocation of subcarriers to users, the model performs closely with Zhang's model. The GA application of current algorithm performs better than Zhang's [13] conventional algorithm and Wang's [23] GA application (see Fig 6). The research discusses two cases; increasing the chromosome length without changing number of users and increase the number of users with same chromosome length. The better results for optimum power allocation will be obtained if we replace the population of low fitness chromosomes with the chromosomes replaced with good genes.

APPENDIX A

(Genetic Algorithm Terminology)

alleles: The chromosomes are composed of genes, which may be represented by 0 or 1.

cardinality: The cardinality is the number of alphabet characters in a scheme. For example, in the binary alphabet {0, 1} cardinality is 2 and the number of elements are 3, because we can add another symbol * - do not care (can take 0 or 1), If the length of the string is 5, that is represented as = {10101}, there are 35 different similarity templates (schemata) can be created.

crossover: Crossover is a recombinant operator that takes two individuals, and cuts their chromosome strings at some randomly-chosen position. This produces two head segments and "tail" segments. The tail segments are then swapped over to produce two new full length chromosomes.

```
xxx|xxxxx      xxx00000
000|00000      000xxxxx
```

The two offspring each inherit some genes from each parent. This is *single point crossover*.

Crossover is not necessarily applied to all pairs of individuals selected for mating. A choice is made depending on a probability specified by the user; this is typically between 0.6 and 1.0. If the crossover is not applied, the offsprings are simply duplications of the parents.

genotype: In natural systems, one or more chromosomes combine to form the total generic prescription for the construction and operation of some organism. The total genetic package is called the genotype.

mutation: Substitute one or more bits of an individual randomly by a new value (0 or 1)

```
10010010 1001010101
         ↓
10010010 0001010101
```

fitness function: A fitness function must be devised for each problem; given a particular chromosome, the fitness function returns a single numerical fitness value, which is proportional to the ability, or utility, of the individual represented by that chromosome.

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