A Novel Cognitive Engine Based on Genetic Algorithm

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***Abstract*—In this paper, we propose a novel cognitive engine based on genetic algorithm (GA). Unlike conventional GA-based cognitive engines, the proposed cognitive engine takes the frequency band of the secondary user as one of the transmission parameters to be optimized, allowing the proposed cognitive engine to choose the optimal frequency band among the vacant bands detected via the spectrum sensing. Numerical results demonstrate that the proposed cognitive engine well optimizes the transmission parameters for a given transmission scenario.**

Keywords-cognitive engine; genetic algorithm; transmission parameter; optimization

I. INTRODUCTION

The increasing demand for high-speed multimedia services has led to the advent of various wideband wireless communication systems including long term evolution (LTE), IEEE 802.16, digital video broadcasting (DVB), and Wi-Fi. As the number of the wideband wireless communications and associated subscribers increases, the spectrum deficiency problem is inevitable since the frequency spectrum is a limited resource. To resolve the problem, the dynamic spectrum access (DSA) technique, which opportunistically utilizes an underutilized frequency band, has been proposed by virtue of the software defined radio (SDR) capable of tuning its transmission parameters [1].

A secondary user (SU) observes the surrounding environments, and subsequently, adjusts its transmission parameters (e.g., the transmit power, modulation index, and transmission bandwidth) based on the observation. Specifically, the SU first determines if a primary user (PU) is utilizing the spectrum band of interest via a spectrum sensing [2]. Then, the transmission parameters of the SU are optimized by an intelligent signal processing unit referred to as a cognitive engine. The implementation of the cognitive engine has been studied mainly based on the artificial intelligence (AI) techniques such as the genetic algorithm (GA), expert systems, neural networks, and case-based reasoning [3]. Especially, the GA-based cognitive engine has attracted much attention since it is capable of self-evolution as the human cognition process unlike other AI-based cognitive engines [4].

In wideband wireless environments, a wideband spectrum is generally interpreted as a set of multiple narrowbands. Thus, after the vacant narrowbands are identified via the spectrum sensing, the cognitive engine should choose an optimal narrowband out of the vacant ones. Thus, in this paper, we consider the frequency band of an SU as one of the transmission parameters to be optimized, and subsequently, propose a cognitive engine by designing a multiple objective fitness function that includes the frequency band of the SU as a transmission parameter, and then, applying the fitness function to the genetic algorithm.

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The rest of this article is organized as follows. Section II introduces the transmission parameters and the cognitive engine system model. Then, in Section III, a multiple objective fitness function is proposed taking the frequency band of SU as a transmission parameter. Section IV demonstrates that a cognitive engine employing the proposed fitness function appropriately optimizes the transmission parameters, and finally, Section V concludes the paper.

II. RELATED WORK

Several studies on the GA-based cognitive engine have been researched focusing on how to optimize the transmission parameters of the SU [5]-[10]. In [5] and [6], an initial version of a GA-based cognitive engine was implemented as a hardware test-bed proving its usefulness as a cognitive engine. To deal with various transmission scenarios, in [7], a multiple objective fitness function is designed as a weighted sum of single objective fitness functions. Recently, to optimize the multiple objective fitness function, cognitive engines have been proposed by employing various evolutionary algorithms such as artificial bee colony algorithm, ant colony optimization, and Biogeography-based optimization instead of GA [8]-[10]. However, the conventional researches were focused on the transmission parameter optimization after the spectrum assignments have been determined, and thus, the frequency band of an SU has not been optimized as a transmission parameter.

III. SYSTEM MODEL

Transmission parameters are the variables to be optimized based on information in environment parameters (e.g., the noise density and the value of the test statistic used in the spectrum sensing). In this paper, we consider the following transmission parameters: the transmit power P_s of SU, modulation index M, bandwidth B_s of the SU signal, and index k of the frequency band that is detected as a vacant band via the spectrum sensing.

To optimize the transmission parameters using GA, we first design a structure of the chromosome as a bit stream

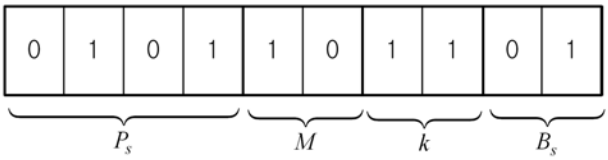

Figure 1. The structure of a chromosome representing the transmission parameters.

representing the values of the transmission parameters. For example, we can design a chromosome as a bit stream with a length of 10, where 4, 2, 2, and 2 bits are used to represent the values of P_s, M, k, and B_s, respectively, as shown in Fig. 1. In this case, we are dealing with 16, 4, 4, and 4 candidates for P_s, M, k, and B_s, respectively. Then, a multiple objective fitness function is defined to measure the desirability of a solution for a transmission scenario of interest. The multiple objective fitness function f can be expressed as

$$f = a_1 f_1 + a_2 f_2 + ... + a_L f_L, \qquad (1)$$

where $\{f_l\}_{l=1}^{L}$ are the single objective fitness functions and $\{a_l\}_{l=1}^{L}$ denote the weight values for $\{f_l\}_{l=1}^{L}$ and $\sum_{l=1}^{L} a_l = 1$ [7]. A transmission scenario determines the value of weights $\{a_l\}_{l=1}^{L}$ by assigning a higher (lower) weight to the single objective fitness function with higher (lower) priority. Finally, the GA provides an optimum solution maximizing the designed fitness function. Specifically, a fitness value of an initial set of the transmission parameter values is calculated, and then, searches for an optimum set by using the selection, crossover, and mutation operations.

IV. PROPOSED FITNESS FUNCTION

The procedure to design a multiple objective fitness function in a form of (1) is to determine single objective fitness functions and associated weight values. We first design single objective fitness functions that affect the data transmission performance of the SU including bit error rate (BER) and throughput. The smaller value of BER guarantees the more reliable performance of the SU, and thus, a single objective fitness function f_{BER} is designed as

$$f_{\text{BER}} = \frac{\log_{10}(0.5) - \log_{10}(P_b)}{\log_{10}(0.5) - \log_{10}(P_{b,\min})}, \qquad (2)$$

where P_b is the BER and $P_{b,\min}$ is the minimum value of $\{P_b\}$ for the given candidates of the transmission parameters. When the BER P_b is expressed in terms of E_b/N_0, where E_b and N_0 denote the bit energy and the noise density, respectively, P_b can also be expressed in terms of the transmission parameters by substituting $\frac{2P_s}{B_s \times \log_2(M) \times N_0}$ for E_b/N_0. On the other hand, the throughput of the data transmission is proportional to the modulation index M, thus, a single objective fitness function $f_{\text{throughput}}$ can be expressed as

$$f_{\text{throughput}} = \frac{\log_2(M) - \log_2(M_{\min})}{\log_2(M_{\max}) - \log_2(M_{\min})}, \qquad (3)$$

where $M_{\max}$ and $M_{\min}$ are the maximum and minimum values of $\{M\}$, respectively. The function is maximized (minimized) when $M = M_{\max}$ ($M = M_{\min}$).

It is also desired to reduce interference to the PU signal, which depends on the power P_s and bandwidth B_s of the SU signal. Thus, we design a single fitness function $f_{\text{interference}}$ as

$$f_{\text{interference}} = 1 - \frac{1}{2}\left\{\left(\frac{P_s - P_{s,\min}}{P_{s,\max} - P_{s,\min}}\right) + \left(\frac{B_s - B_{s,\min}}{W(k) - B_{s,\min}}\right)\right\}, \qquad (4)$$

where $P_{s,\max}$ and $P_{s,\min}$ are the maximum and minimum values of $\{P_s\}$, respectively, $W(k)$ is the bandwidth of the kth narrowband assigned to the PU, and $B_{s,\min}$ is the minimum value of the bandwidth candidates B_s.

Now, we will discuss how to obtain the optimal value of k and design a single objective fitness function. It is naturally assumed that the test statistic value $T(k)$ and the threshold $\gamma(k)$ for the spectrum sensing of the kth band is known to the cognitive engine, and the bandwidth $W(k)$ is a priori knowledge. Although the candidate narrowbands are detected as a vacant band by the spectrum sensing process, some of the narrowbands may be occupied by the PU signal due to the missed detection of the spectrum sensing. Thus, we design a term $\left(\frac{D(k) - D_{\min}}{D_{\max} - D_{\min}}\right)$, where $D(k) = \gamma(k) - T(k)$, and $D_{\max}$ and $D_{\min}$ are the maximum and minimum values of $\{D(k)\}$, respectively, based on the observation that the frequency band is more likely to be vacant when the difference between $\gamma(k)$ and $T(k)$ is a larger value. It is noteworthy that $D(k) > 0$ since the narrowbands of interest are already detected as a vacant band (i.e., $\gamma(k) > T(k)$) in the spectrum sensing process. Moreover, to choose a wide frequency band and to fully use the selected frequency band, we also design two terms $\left(\frac{W(k) - W_{\min}}{W_{\max} - W_{\min}}\right)$ and $\left(\frac{B_s - B_{s,\min}}{W(k) - B_{s,\min}}\right)$, where $W_{\max}$ and $W_{\min}$ are the maximum and minimum values of $\{W(k)\}$, respectively, and $B_{s,\max}$ is the maximum

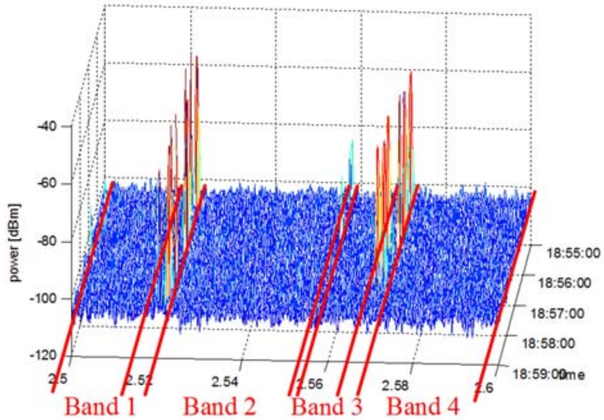

Figure 2. The frequency spectrum of [250 MHz, 260 MHz] bands.

value of the bandwidth candidates B_s of the SU. Normalizing and combining the designed terms, we propose a single objective fitness function f_{band} as

$$f_{\text{band}} = \frac{1}{3}\left(\frac{D(k)-D_{\min}}{D_{\max}-D_{\min}}\right)+\frac{1}{3}\left(\frac{W(k)-W_{\min}}{W_{\max}-W_{\min}}\right) + \frac{1}{3}\left(\frac{B_s-B_{s,\min}}{W(k)-B_{s,\min}}\right). \quad (5)$$

In summary, the function f_{band} is designed (i) to maximize the probability that the chosen band is vacant, (ii) to choose a band with a larger bandwidth, and (iii) to transmit the SU signal with a larger bandwidth.

Finally, we propose a multiple objective fitness function as

$$f_{\text{WB}} = w_1 f_{\text{band}} + w_2 f_{\text{BER}} + w_3 f_{\text{throughput}} + w_4 f_{\text{interference}}, \quad (6)$$

where $\{w_l\}_{l=1}^{4}$ are the weight values for fitness functions for f_{band}, f_{BER}, $f_{\text{throughput}}$, and $f_{\text{interference}}$, and $\sum_{l=1}^{4} w_l = 1$.

V. NUMERICAL RESULTS

In this section, we explain the cognitive engine simulator that we have developed and show the results on the transmission parameter optimization. We measured a frequency spectrum of [250 MHz, 260 MHz] bands at the top of a mountain and used the measured data as the input of the simulator. The spectrum is shown in Fig. 2, where four spectrum bands (Band 1 ~ Band 4) are detected as the vacant narrowbands. The simulator is developed using Matlab graphic user interface (GUI) programming and its main screen is shown in Fig. 3.

For simulations, we assume the following parameters: a chromosome with a length of 10 bits, where 4, 2, 2, and 2 bits are used to represent the values of P_s, M, k, and B_s,

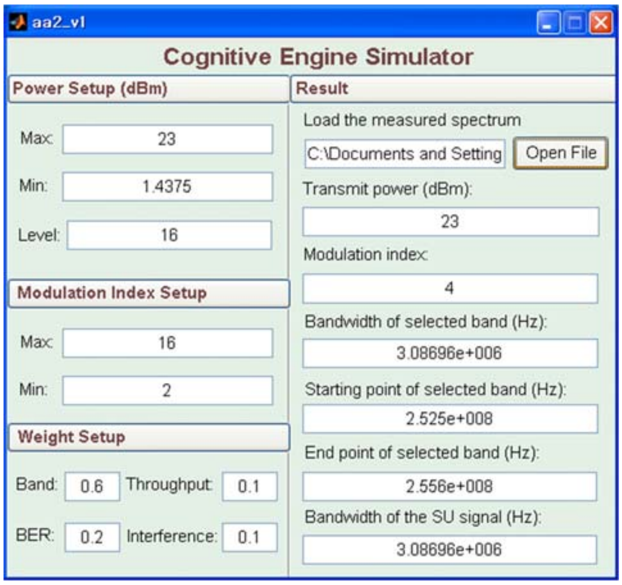

Figure 3. The cognitive engine GUI simulator.

respectively. The candidates for P_s, M, k, and B_s are set to represent $\{\frac{23}{16}, \frac{2\times 23}{16}, \ldots, 23\}$ dBm, $\{2,4,8,16\}$, {Band 1, Band 2, Band 3, Band 4}, and $\{10,100,500,W(k)/10^3\}$ kHz, respectively. The noise density N_0 is calculated as the power spectral density of a frequency band with the lowest power over the spectrum range of [200 MHz, 300 MHz], then, the threshold for the spectrum sensing is determined to satisfy the false alarm probability of 0.01. The spectrum sensing is performed via the energy detector.

For the transmission scenarios, we first consider the simplest case that $\overline{w} = [w_1, w_2, w_3, w_4] = [1,0,0,0]$ to verify the simulator, and subsequently, we demonstrate the results for a scenario with the weight vector $[0.6, 0.1, 0.2, 0.1]$ as an example. Fig. 4 shows (a) the fitness value and (b) the result solution of the simulator when $\overline{w} = [1,0,0,0]$. From the figure, we can see that the fitness value becomes saturated as the generation increases. Also, the 7th and 8th bits of the chromosome are '01' and the 9th and 10th bits are '11' representing that Band 2 (the largest vacant band) is chosen as the frequency band and the SU uses the whole spectrum of Band 2. However, the transmit power (the 1st-4th bits) and the modulation index (the 5th and 6th bits) are randomly selected by the GA since the fitness function f_{band} is not a function of P_s and M.

Fig. 5 shows (a) the fitness value and (b) the result solution of the simulator when $\overline{w} = [0.6, 0.2, 0.1, 0.1]$. Since the weight value for f_{band} is the largest, Band 2 is chosen as the frequency band and the SU uses the whole spectrum of Band 2 as in the case that $\overline{w} = [1,0,0,0]$; however, for the transmit power P_s and the modulation index M, the maximum power of 23 dBm and QPSK modulation is

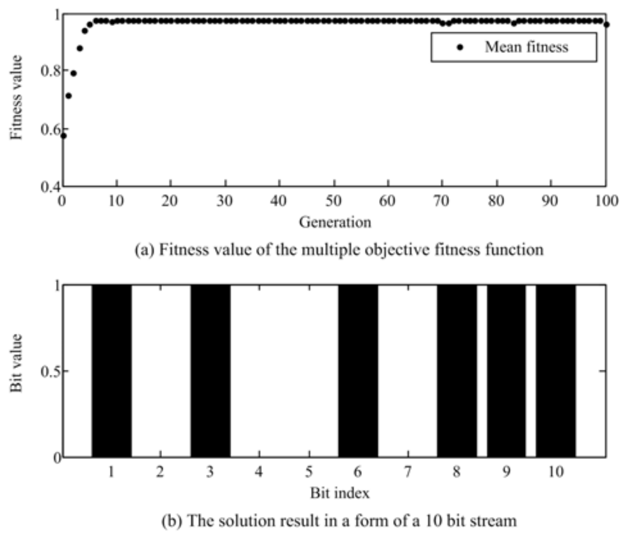

Figure 4. Simulation results when $\overline{w} = [1, 0, 0, 0]$.

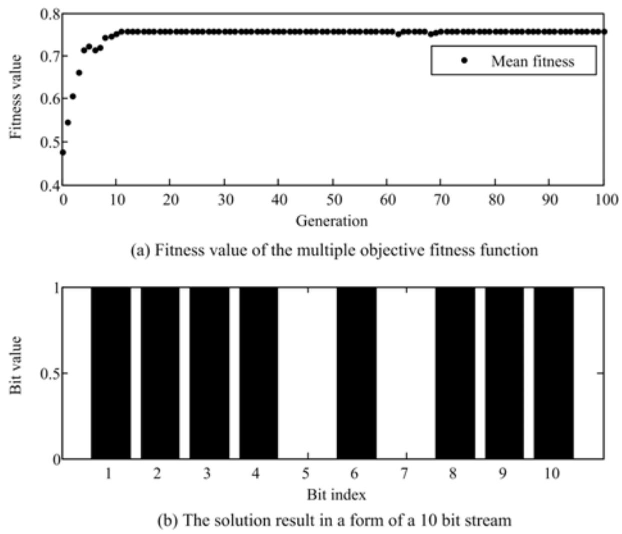

Figure 5. Simulation results when $\overline{w} = [0.6, 0.1, 0.2, 0.1]$.

selected considering the fact that the weight value for f_{BER} is the second largest.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a GA-based cognitive engine suitable for the wideband wireless communications. Including the frequency band of the SU as a transmission parameter to be optimized, we have designed a multiple objective fitness function that measures the desirability of a solution, and then, applied the fitness function to the GA. From numerical results, it has been confirmed that the proposed cognitive engine appropriately optimizes the transmission parameters for a given weight vector describing the transmission scenario. To implement a cognitive engine, it is also required to optimize the weight vector $\overline{w}$ as well as the transmission parameters, which is our future research topic.

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