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Cellular Networks Pollution Reduction

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ABSTRACT

The potential of adaptive antennas to optimize the wireless network performance make it one of the promising technologies that can face the increased demand for wireless communications services with the limited available bandwidth. Adaptive antennas have the ability to steer their main lobe in the direction of interest and placing nulls in the direction of interference. This can result in co-channel interference minimization, maximizing Signal to Interference Ratio (SIR) and then improve the receiver sensitivity.

In this paper, the base-station sensitivity improvement and its effect on the mobile transmit power were investigated at different scenarios. Results show that using adaptive antenna yields in RF pollution reduction.

Keywords: RF pollution reduction; cellular communication networks; SIR.

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الحد من تلوث الشبكات الخلوية

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المستخلص

إمكانيات الهوائي التكيفي في الحصول على أقصى أداء للشبكات اللاسلكية جعلته واحد من وسائل التكنولوجيا الواعدة التي يمكن أن تواجه الطلب المتزايد على خدمات الاتصالات اللاسلكية ضمن الحزمة المحدودة العرض. يمتلك الهوائي التكيفي القابلية على تدوير فصوصه الرئيسية بالاتجاه المطلوب ووضع الأصفار باتجاه مصدر التداخل. ينتج عن ذلك تقليل التداخل بين الخلايا التي تعمل بنفس القنوات, زيادة نسبة الإشارة الى الضوضاء و من ثم تحسين حساسية المستقبل.

في هذا البحث, تحسين حساسية محطة القاعدة وتأثيرها في القدرة المرسلة من الهاتف النقّال تم اختبارها بسيناريوهات مختلفة. بينت النتائج المعروضة بان استعمال الهوائي التكيفي ينتج عنه تقليل التلوث الراديوي.

1. Introduction

Base stations in conventional cellular communication networks use either omnidirectional antennas or sectored antennas. In these networks, most of the power is radiated in other directions than toward the desired user as there is no information about mobile units (users) locations. The power radiated in other directions can be regarded as a waste of power, and experienced as interference by users in co-cells, i.e. those cells using the same set of radio channels [1] [2].

Widespread utilization of cellular mobile communications services results in the concentration of more base stations installed in populated and commercial areas to provide good coverage. Cellular base stations use directional antennas to transmit through several carrier frequencies, resulting in a power of several kilowatts may be transmitted in the main beam direction. This increases the public concern about the effects of electromagnetic radiation on the exposed biological tissues and may result in many electromagnetic compatibility (EMC) problems [3].

This study concentrates on the benefits regarding the RF radiation reduction obtained through the use of adaptive antennas.

The paper is organized as follows: A brief concept of the adaptive antenna system and its benefit is described in Section II. Section III describes the mathematical derivation of the signal to noise ratio (SNR). The impact of RF radiation reduction on RF pollution mitigation is given by simulation in section IV. Conclusions and future work are mentioned in Section V.

2. Adaptive Antenna Technology

The adaptive antenna is an array of antennas with a digital signal processing unit. The whole system can be viewed as a single antenna with a flexible radiation pattern that dynamically varies in response to the radio environment. The transmitted signal is directed toward the intended or the desired user, and nulls are placed in the direction of interferers [1-3]. The signals received at the array elements are multiplied by the complex weights and then summed up to obtain the desired radiation pattern. The complex weights that are determined by the processing unit are continuously adjusted by the signal processing unit which uses the available properties of the desired signal to calculate the weights [4]. Utilizing the initial information about the signal characteristics such as a direction of arrival (DOA), adaptive algorithms can adjust the array weights dynamically with respect to signal environment and perform the desired radiation pattern [5]. Uniform linear array with N antenna elements is assumed to receive uncorrelated signals from K sources. The input signal vector x(t)can be expressed as:

$$x(t) = \sum_{k=1}^{K} a(\theta_k)\, S_k(t) + n(t) \qquad (1)$$

where$_k$(t) is K ×1 vector concerning to the k-th source located at direction θ_k from the array, a (θ_k) is the N×1 steering vector of the array for the direction of θ_k that can be written as:

$$a(\theta_k) = [1 \quad e^{-j\beta d sin\theta_k} e^{-j2\beta d sin\theta_k} \quad \ldots \quad e^{-j(N-1)\beta d sin\theta_k}] \qquad (2)$$

where is the inter-element spacing that is assumed to be equal to (λ/2), and β=2π/λ.

The array output y(t) can be generated through the adjustment of the complex weight vectors as shown in Figure 1.

$$y(t) = \sum_{m=1}^{N} x(t)\, w^H(t) \qquad (3)$$

where (w^H)denotes the transposition of the complex conjugate vector.

Many algorithms are used in many papers such as [4], [5], and [6] to determine and update the uplink weight vectors for performing beamforming on the received signals. In this study, Normalized Least Mean Square (NLMS) algorithm is employed due to its reliable results in stability.

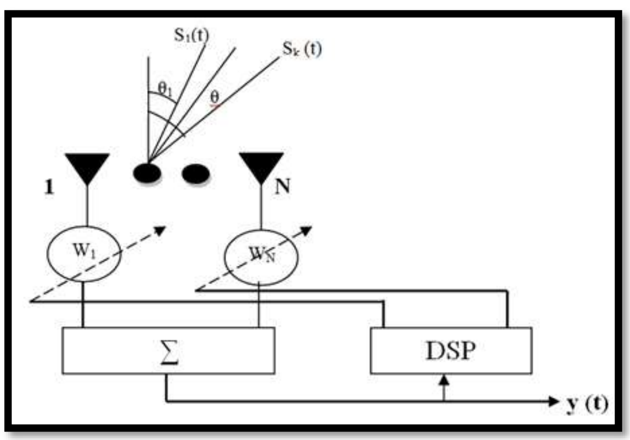

Fig. 1: Adaptive Antenna Construction.

3. Derivation of Signal to Noise Ratio (SNR)

The output at each antenna element in the adaptive array is phase shifted by multiplication with the weight coefficients, and these outputs will be positively combined to increase the signal amplitude increases N times.

In the uplink, the amplitude of the received signal from the i-th user at any cell and the noise at the base station will be given as:

$$\text{Signal received by basestation} = \sum_{m=1}^{N} r_m = N_r$$

$$Noise = n = n_1 + n_2 + n_3 + \cdots + n_N = N_n$$

$$SNR = \frac{(Nr)^2}{Nn^2} = \frac{N^2 r^2}{Nn^2}$$

$$= N\frac{r^2}{n^2} \qquad (4)$$

In the worst-case scenario when the signal power and noise power are the same (r=n), the signal to noise ratio (SNR) can be given as:

$$SNR = N \qquad (5)$$

The base station receiver sensitivity S can be given in terms of the carrier power C, and the total interference I_t as ($S = C/I_t$)

Adaptive antenna usage at the base station can be characterized by a reduction in C/I ratio or the sensitivity required by the receiver. If the receiver sensitivity is reduced from S1to S2, a capacity increase of (β) and a power reduction of (δ) can be obtained, as follows [3]:

$$S_1 = \frac{C}{I_t} = \frac{C}{I_{MAI} + n}$$

where C is the carrier power, It is the sum of multiple access interference (I_{MAI}) from the same cell (intra-cell) and other cells (inter-cell), and n is the noise power.

$$S_2 = \frac{\delta\, C}{(1-\alpha)\, I_t \;+ \beta\, \delta\, \alpha I_t} \quad \Longrightarrow \quad \frac{S_1}{S_2} = \frac{C}{I_t} \cdot \frac{(1-\alpha)\, I_t \;+ \beta\, \delta\, \alpha\, I_t}{\delta\, C}$$

$$\delta = \frac{1-\alpha}{(S_1 / S_2) - \beta \alpha} \tag{6}$$

where α is the cell load that is equal to the ratio of active users to the maximum allowable number of users expressed in terms of percentage of capacity.

A. Receiver Sensitivity Improvement

As can be noticed from equation 6, the use of adaptive antenna has the ability to decrease the base station receiver sensitivity by a magnitude that is equivalent to the additional diversity gain obtained in up-link without capacity extension. Figure 2 shows the obtained power reduction (α) due to adaptive antenna usage at different load factors. It can be seen that in a 40% loaded system, a 6.0 dB receiver sensitivity improvement could lead to a 7.75 dB power reduction. The same receiver sensitivity could lead to about 9.27 dB in 60% loaded system, and 12.0 dB in 80% loaded system. This can allow the receiver to receive a weaker signal from the cell phones and can be translated into cellphone battery life extension and radiated power density reduction around the head of the cell phone user.

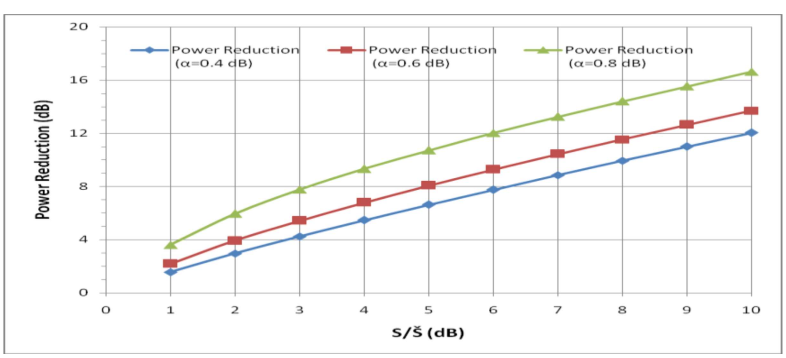

Figure 2: Power Reduction Effects on Receiver Sensitivity

The adaptive antenna with ten elements at the base station would need (1/10) the power transmitted by the cell phone to produce the equivalent radiation of a single antenna base station. On the other hand, when the power transmitted by the mobile phone remains the same as the adaptive antenna array of N elements at the base station, the cost of the amplifier required at the base station will reduce.

Therefore, the use of adaptive antenna has the ability to decrease the base station receiver sensitivity by a magnitude that is equivalent to the additional diversity gain obtained. This can allow the receiver to receive a weaker signal from the cell phones, and this can be translated into cell phone battery life extension and capacity improvement.

B. RF Pollution Reduction

Keeping the size of the area covered by a base station, the adaptive antenna can be used to reduce the actual power transmitted by the base station. Replacing an antenna with a gain of (G_1) by another antenna with a gain of (G_2) allows reducing the actual transmitting power from (P_1) to (P_2), with the same effective transmitted power (ERP).

$$(ERP)_1 = P_1\, G_1 \quad , \quad (ERP)_2 = P_2\, G_2$$

$$P_2 = P_1 \frac{G_1}{G_2} = P_1 \frac{G_1}{N\, G_1} = P_1 \frac{1}{N} \qquad (7)$$

Equation (8) implies that the transmitted power of the base station can be reduced by a factor of (1/N).

The power density (P_d) at any distanced from the base station antenna can be given as:

$$P_d = \frac{P\, G}{4\, \pi\, d^2} \qquad (8)$$

Where P is the power transmitted by the base station through an antenna with a gain of G is an antenna gain.

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$$(P_d)_1 = \frac{P_1 \, G_1}{4\,\pi\, d^2} \quad ,(P_d)_2 = \frac{P_2 \, G_2}{4\,\pi\, d^2}$$

$$\frac{(P_d)_2}{(P_d)_1} = \frac{1}{N} \tag{9}$$

This implies that the exposer of any object to the electromagnetic radiation emitted by the base station antenna will be reduced by (1/N).

Figure 3 shows the power density against the number of antenna elements used at the base station when a power of ten watts is transmitted through an antenna of 18 dBi gain. It can be noticed that the power density at a distance of 20m from the base station antenna is equal to 1.255mW/cm^2 when one antenna is used, while it decreases to 0.627mW/cm^2 when an array of two elements is used, a value of 0.313 mW/cm^2 with a base station of four elements, the use of eight elements array produces a 0.016mW/cm^2, and a 16-elements array gives 0.785 µw/cm^2.

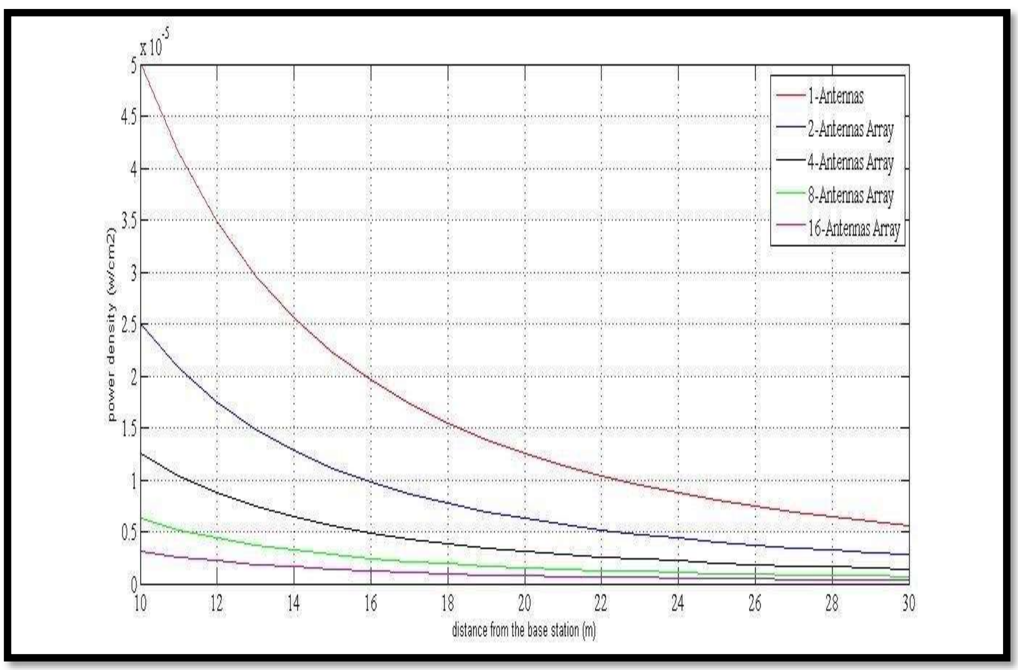

Figure 3: Power density vs adaptive array elements

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C.Base Stations Density Reduction

With adaptive antenna application, the excessive gain that is equivalent to the number of antenna array N will increase the highest allowable path loss level. With the adaptive antenna, the maximum path loss will be achieved at a distance (d_2) that is greater than the distance (d_1) obtained with the use of the single antenna element.

$$P_r(d) = P_t\, G_t\, G_r\, \frac{h_b^{\,2}\, h_m^{\,2}}{d^4}$$

$$path\,loss = \frac{P_r}{P_t} = P_L(d) = G_t\, G_r\, \frac{h_b^{\,2}\, h_m^{\,2}}{d^4}$$

$$[P_L(d_1)]_{dB} = G_t + G_r + 20\log(h_b\, h_m) - 40\log(d_1)$$

$$[P_L(d_1)]_{dB} = G_t + 10\log(M_m) + G_r + 20\log(h_b\, h_m) - 40\log(d_2)$$

For range extension without power reduction: $[P_L(d_1)]_{dB} = [P_L(d_1)]_{dB}$

$$G_t + 10\log(N_m) + G_r + 20\log(h_b\, h_m) - 40\log(d_2) = G_t + 20\log(h_b\, h_m) - 40\log(d_1)$$

$$10\log(N_m) = -40\log(d_1) + 40\log(d_2)$$

$$10\log(N_m) = 40\log(d_2 / d_1)$$

$$(d_2 / d_1) = Range\,Extension = \sqrt[4]{N} \quad = N^{1/4}$$

Assuming circular cell, the area covered by a base station with a single antenna will be $(\pi\, d_1^{\,2})$, the area covered by a base station with an adaptive array will be $(\pi\, d_2^{\,2})$, and the coverage extension will be

$$Coverage\,Extension = \frac{\pi\,(d_2)^2}{\pi\,(d_1)^2} = \left(N^{\frac{1}{4}}\right)^2 = \sqrt{N} \qquad (10)$$

If the total area required to be covered by the cellular network is assumed to be A and the system base stations are distributed uniformly, the required base station for full coverage will be reduced by $(A/\pi\, d_1^{\,2})$ with single antenna base station against $(A/\pi\, d_2^{\,2})$ with the use of the adaptive antenna. This will reduce the required number of base stations.

$$\text{Base Station reduction} = \frac{A/\pi\ d_2^{\,2}}{A/\pi\ d_1^{\,2}} = 1/\sqrt{N} \tag{11}$$

This means that the required number of the base station will be reduced $(1/\sqrt{N})$, and this, in turn, will reduce the number of electromagnetic radiation sources.

D. Frequency Reuse Efficiency Improvement

The interference is one of the main limiting factors in cellular network capacity. The frequency reuse efficiency f has defined the ratio of the other-cell interference power I_{oc} to the same-cell interference power I_{sc}. Interference level reduction can increase the maximum number of supportable users in a cellular system.

$$f = \frac{I_{OC}}{I_{SC}} \tag{12}$$

Assuming omnidirectional base stations network of a total coverage area of a radius R, and the users are uniformly distributed in each network cell. The distance between any user at any cell and the serving base station denoted r_u. The power received by mobile at distance r_u from its serving base station will represent the user contribution in same cell interference (I_{sc}). It can be given as

$$P_{ru} = P_t\ K\,(r_u)^{-\gamma} = I_{sc} \tag{13}$$

where K is a constant that depends on the antenna heights, the antenna gains, and the operating frequency, γ is the power exponent value, P_{ru} is the power received by the mobile phone, and P_t is the power transmitted by the serving base station. Each elementary surface ($z\ dzd\theta$) at a distance z from the desired user contains ($\rho BSzdzd\theta$) base stations which contribute in other cell interference as shown in Figure 6.

$$I_{oc} = \int_0^{2\pi}\int_{2R_c}^{R} \rho_{BS} P_t\, K\, z^{-\gamma}\ z\, dz\, d\theta \tag{14}$$

$$I_{oc} = K P_t \rho_{BS} \int_{0}^{2\pi} \int_{2R_c}^{R} z^{1-\lambda} \, dz \, d\theta$$

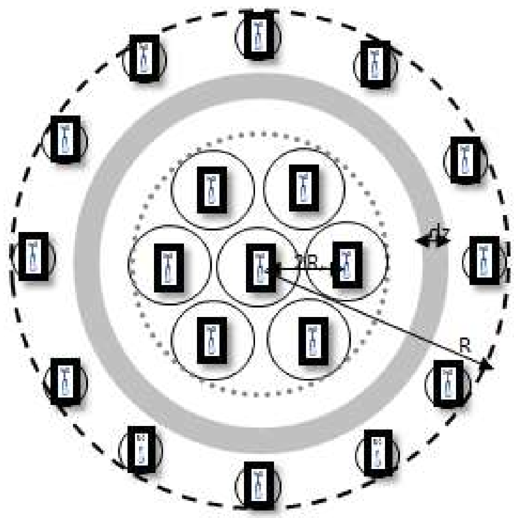

Figure 4: frequency reuse

4. Conclusions

For wireless communications, a smart antenna system offers several advantages over conventional antennas. These include range extension, capacity increasing lower power consumption. The impact on power reduction at mobile base station has been presented. It has been noticed that gain obtained by using smart antenna leads to reduce the cellular phone transmitted power and its effect on the human brain, which means the reduction of Pollution caused by RF radiation. The power reduction will contribute to cellular base-station network reduction.

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