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POWER CONSUMPTION IMPROVEMENT FOR GREEN CELLULAR MOBILE COMMUNICATIONS

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Abstract: The increasing demand for cellular communication services requires high number of cellular base stations distributed over land resulting in greater demands on energy usage, and high pollution levels. Recently, because of the public concern about the electromagnetic radiation effects and energy costs, providing efficient green cellular communication services through power consumption and keeping RF pollution at harmless levels become one of the major aims for cellular network operators. This paper presents the intelligent antenna technology as one of the solutions for energy consumption reduction in cellular base stations, base station density reduction and cell phone battery life extension. Results presented show that using intelligent antenna yields in base station power reduction at different cell loads, and cell phone battery life extension**.**

Keywords: *green cellular network, energy saving, intelligent antenna system, battery life extension, RF Safety.*

تحسين استهلاك القدرة في الخلايا الخضراء للاتصالات المتنقلة

الخلاصة: أدى الطلب المتزايد على خدمات الاتصالات الخلويه الى زيادة محطات القاعدة الموزعة على الارض و زيادة الطلب على الطاقه ومستوى التلوث. حاليا وبسبب القلق من تأثيرات الاشعاعات الكهرومغناطيسية ومن الكلفة المتزايدة للطاقة يجري الاعداد لخلايا خضراء لتقليل مستوى التلوث واستهلاك القدرة. يقدم هذا البحث تكنولوجيا الهوائي الذكي كحل لتقليل القدرة في محطات القاعدة وتقليل اعدادها ايضا وتبين النتائج انه يمكن تقليل القدرة باختلاف حمل الخلايا ويمكن ايضا اطالة عمر بطارية الهاتف.

1. Introduction

In Iraq, cellular communication service providers such as Zain, Asiacell, and Korectel have placed hundreds of mobile base station all over the country, most of which are placed on the houses rooftops.

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The numbers of cellular base stations are still growing in residential areas to meet the subscriber's continuous demand for broadband data transmission services through their cell phones. Placing base station far from the users will result in poor communication quality and the cell phone should increase its output power to sustain the connection decreasing the phone battery life [1-2].

The widespread of cellular base stations in residential areas has caused concerns regarding the probable health risk resulting from long-term exposure to base station electromagnetic energy [3-4].

In cellular networks, the power consumption is mainly drawn by network base stations, and the base stations density is expected to be increased to meet the subscribers demands. Therefore, consumed power reduction of base station becomes important issue for cellular service operators especially in developing countries where diesel generators are used.

Greening of cellular communication networks became one of the main aims for cellular operators to maintain profitability, and to provide safe communication services with low overall environment effects [5,6].

If we can improve the base station sensitivity or reduce their radiated power, this would translate into cell phone battery life extension and/ or reduced the base stations density at the required coverage area to reduce RF pollution levels.

One of the popular technologies improving the power consumption of cellular networks is to use intelligent antenna systems that have the potential to reduce the transmitted power of the transceivers.

This paper concentrates on intelligent antenna potentials in base station power reduction, base stations density reduction, and cell phone battery life extension.

The paper is organized as follows: Section II presents a brief description of intelligent antenna systems. Section III describes the mathematical derivation of signal to noise ratio (SNR). The impact of power reduction on cell phone battery life, and RF pollution mitigation is given by simulation in section IV. Conclusions and future work are mentioned in Section V.

2. Intelligent Antenna Technology

The current cellular networks deploy a large number of small cells; each cell is served by a base station using a conventional antenna system to achieve best coverage. The current cellular networks are not energy efficient, as the power radiated by base stations in other directions than toward the desired user can be regarded as a waste of energy and result in interference increasing.

Intelligent antenna is one of the most promising technologies that are used in the third and fourth generations (3G),(4G) cellular communications networks to meet the growth demand for wireless broadband data transmission with the limited radio frequency spectrum.

Intelligent antenna is an array of antennas terminated into an intelligence adaptive signal processing unit that have the ability to change its pattern dynamically so that the antenna main beam tracks the desired user and suppress the interferers. The signals received at the antenna array elements are multiplied with a weight, adjusting phase and amplitude, then the weighted signals are summed up to obtain the output signal. The weights are continuously adjusted by intelligence adaptive signal processing unit that uses the received signal available information to calculate the weights. Adaptive algorithms can adjust the array weights dynamically with respect to signal environment and perform the desired radiation pattern [7].

Linear array with M antenna elements is assumed to receive uncorrelated signals from S sources (mobiles) in up-link. The input signal at any antenna element of the base station that have real part and imaginary part of the complex received signal $x_{m,n}$, can be expressed as

$$x(m,n) = \sum_{s=1}^{S} x_s(n) + N(n) \tag{1}$$

where m denotes the antenna element number ($m = 1, 2. . . , M$), n denotes the time instant, $x_s(n)$ is S ×1 vector concerning to the s-th source located at direction θ_s from the base station antenna, and N is the noise at the antenna element.
These received signals are weighted by appropriate weights ($w_{m,n}$) to obtain the output signal $y(t)$ that is given as

$$y(t) = \sum_{m=1}^{M} x(n)\, w^H(n) \tag{2}$$

The difference in received signal path between the first element and the m-th element will be equal to $(m-1)\, d \sin\theta_s$, where d is the inter-element spacing. This path difference will produce a phase shift of $(m-1)\, k\, d \sin\theta_s$ where $k=2\pi/\lambda$.

The array output signal $y(n)$ can be generated through the adjustment of the appropriate complex weight vectors to maximize the power received from the desired source. If the weight coefficients is chosen to equalize the phase shifts between the signals received by antenna array elements, the desired signal received at each antenna element will be phase-shifted due to the weight coefficients, and the signals from all elements will be positively summed up to obtain an output signal whose amplitude is increased by M times. The weight vector can be considered as the steering vector $w(\theta_s)$ that is the M×1 vector of the array for direction of θ_s and can be written as:

$$w(\theta_s) = [1 \quad e^{-j\,k\,d\sin\theta_s} \quad e^{-j\,2k\,d\sin\theta_s} \quad .... \quad e^{-j\,(M-1)k\,d\sin\theta_s}\,] \tag{3}$$

Many algorithms are used in many papers such as [9-11] to determine and update the uplink weight vectors for performing beam forming on the received signals. In this study, Least Mean Square (LMS) algorithm is employed due to its faster convergence rate. The signal path loss P_L at a distance r from transmitter can be expressed with respect to the path loss at a certain distance (r_o), i.e. the reference distance that is close to the transmitter such that multipath and diffraction are negligible [12].

$$P_L(r) = P_L(r_o)\ \left(\frac{r}{r_o}\right)^2 \tag{4}$$

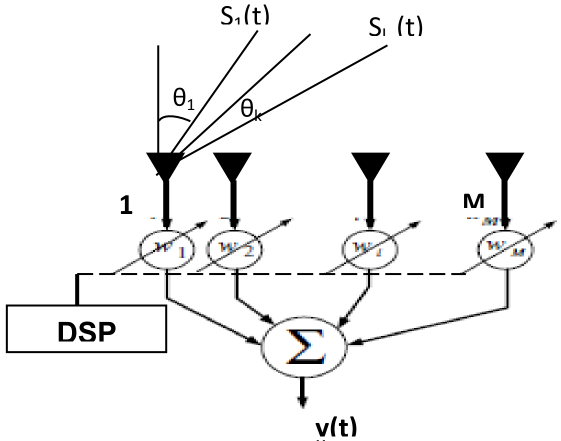

Figure 1. Base Station Intelligent Antenna System.

3. The Effect of Power Reduction

3.1 Signal to Interference Ratio Improvement

In up-link, the mobile transmit power is required to fulfill the required bit energy to interference plus noise density ratio (E_b/N_t) that determine the base station sensitivity, otherwise, it cannot accesses the network, and will be put to outage. In this section, we will focus on evaluating the improvement of base station sensitivity that can be obtained with the use of using intelligent antenna arrays at the base station.

The base station sensitivity S can be characterized in terms of the carrier power C, and the total interference I_{total} as ($\gamma = C/I_{total}$), and the cell load α is characterized by the multiple access interference I_{ma} to total interference giving the ratio of active users to the maximum allowable number of users.

$$\gamma = \frac{C}{I_{SC} + I_{OC} + N} = \frac{C}{I_{total}} \tag{5}$$

$$\alpha = \frac{I_{ma}}{I_{total}} \tag{6}$$

Where I_{SC} is the same cell (intra- cell) interference, I_{OC} is the other cells (inter- cell) interference, and I_{total} is the interference plus thermal noise N. If the base station sensitivity is reduced from γ to γ' with the use of intelligent antenna, a capacity increase of β and a power reduction of δ can be obtained, as follows [9]:

$$\gamma' = \frac{\delta\ C}{(1-\alpha)\ I_{total} + \beta\ \delta\ \alpha I_{total}}$$

$$\frac{\gamma}{\gamma'} = \frac{C}{I_{total}} \cdot \frac{(1-\alpha)\ I_{total} + \beta\ \delta\ \alpha I_{total}}{\delta\ C}$$

$$\frac{\gamma}{\gamma'} = \frac{(1-\alpha) \ + \beta \ \delta \ \alpha}{\delta}$$

$$\delta \, (\frac{\gamma}{\gamma'} - \beta \ \alpha) = (1-\alpha)$$

$$\delta = \frac{1-\alpha}{(\gamma / \gamma') - \beta \alpha} = Power \ \mathrm{Re}\, duction \tag{7}$$

$$(\frac{\gamma}{\gamma'} - \beta \ \alpha) = \frac{1-\alpha}{\delta}$$

$$\beta \ \alpha = \frac{\gamma}{\gamma'} - \frac{1-\alpha}{\delta}$$

$$\beta \ = \frac{\delta \ \frac{\gamma}{\gamma'} + \alpha - 1}{\delta \ \alpha} = Capacity \ \ Extension \tag{8}$$

If the amplitude of each signal received from the *s-th* user (mobile) is equal to *a* at each base station antenna element, each signal will be multiplied by a weight, then these signals are combined to yield the array output. The signal amplitude will increase M times after phase shifting and multiplication by the antenna element weight. When the base station antenna have *M* antenna elements, and the noise level at each element is *N*, then the signal to noise ratio(SNR) can be given as:

$$Signal \ received \ by \ base \ station = \sum_{m=1}^{M} a_m = M \ a$$

$$Noise \ Level = N_1 + N_2 + N_3 + N_4 + .. \ . + ... + ... + N_N = M \ N$$

$$SNR = \frac{(M \ a)^2}{M \ N^2} = \frac{M^2 \ a^2}{M \ N^2} = M \ \frac{a^2}{N^2}$$

When the signal power and noise power are the same (*a*=*N*), the signal to noise ratio (SNR) will be equal to *M*.

$$(SNR)_{dB} = 10 \log_{10}(M) \tag{9}$$

In downlink, if the amplitude of the signal transmitted by each antenna element is *b*, the use of transmit weighting factors will lead to the signals being added together at the cell phone terminal. Assuming that the signals arrive with the same power, the power received at the cell phone will be given as:

$$Signal \ received \ by \ cell \ \ phone = \sum_{m=1}^{M} b_i = M \ b$$

As the cell phone use conventional antenna, the noise power at the cell phone is independent of the antenna weightings. Assuming that the signal and noise power are the same, the SNR can be given as:

$$SNR = \frac{(M\ b)^2}{N^2} = \frac{M^2\ b^2}{N^2} = M^2$$

$$(SNR)_{dB} = 20\log_{10}(M) \tag{10}$$

3.2 Cell phone Battery Life Extension

As the cell phone battery capacity determines the transmitting power and the operating time between charging, it is very necessary to use high capacity battery. The cell phone battery efficiency (η) can be given in terms of input power (P_{in}) i.e. the product of the input current (I_{in}) and the input voltage (V_{in}) and the output power (P_{out}) as:

$$P_{out} = \eta\ P_{in} = \eta\ V_{in} \times I_{in}$$

The battery life can be expressed as a function of input current (I_{in}) as:

$$Battery\ \ Life\ (Hours) = \frac{Battery\ \ (Ah)}{I_{in}} = \frac{Battery\ \ (Ah)}{(P_{in}\ / V_{in})} \tag{11}$$

The diversity gain obtained through the use base station with intelligent antenna systems will enable the power transmitted by the mobile phone to be reduced as the base station will be able to receive a weaker signal. This results in less battery power consumption, more talking time, and even smaller cell phone. If the transmitted power is kept the same, this could translate to a range extension as the excessive gain that is equivalent to the number of antenna array *M* will increase the allowed path loss level by *M*. Therefore, the allowable path loss (P_L) will be achieved at a distance (d_2) that is greater than the distance (d_1) obtained with the use of single antenna element.

3.3 Derivation of Base Station Density Reduction

As the allowable path loss will be increased due to the excessive gain (G)that is equivalent to the number of antenna array *M* , keeping the same transmitted power will be translated to range extension.

$$P_L(r_2) = P_L(r_1) + G$$

$$(G)_{dB} = 10\ \log_{10}(M)$$

$$P_L(r_o) + 10\ \log_{10}\ (\frac{r_2}{r_o})^2 = P_L(r_o) + 10\ \log_{10}\ (\frac{r_1}{r_o})^2 + 10\ \log_{10}(M)$$

$$10\ \log_{10}(M) = 20\ \log_{10}\ (\frac{r_2}{r_o}) - 20\ \log_{10}\ (\frac{r_1}{r_o})$$

$$10\ \log_{10} M = 20\ \log_{10}\ (\frac{r_2}{r_o} . \frac{r_o}{r_1}) = 20\ \log_{10}\ (\frac{r_2}{r_1})$$

$$\log_{10} M^{10} = \log_{10} (\frac{r_2}{r_1})^{20}$$

$$(M^{10})^{\frac{1}{20}} = (\frac{r_2}{r_1})$$

$$\frac{r_2}{r_1} = \sqrt{M} = Range\ Extension$$

The area covered by a base station with a single antenna will be $(\pi\, r_1^{\ 2})$, the area covered by a base station with an intelligent antenna will be $(\pi\, r_2^{\ 2})$, and the coverage extension will be

$$Coverage\ Extension = \left(\frac{\pi\, r_2}{\pi\, r_1}\right)^2 = M \tag{13}$$

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 $(A/\pi\, r_1^{\ 2})$ with single antenna base station against $(A/\pi\, r_2^{\ 2})$ with the use of intelligent antenna. This will result in reduction the required number of base stations.

$$Base\ Station\ reduction = \frac{A/\pi\, r_2^{\ 2}}{A/\pi\, r_1^{\ 2}} = 1/M \tag{14}$$

This means that the required number of base station will be reduced by $(1/M)$, and this in turn will reduce the interference caused by the surrounding base stations, and the total power consumption at base stations.

4. Simulation Results

Figure 2 shows that the potential of intelligent antenna system to maximize the power level (y-axis) in the direction (x-axis) of the desired user. The beam is directed at 45^o while the interferers ($0^o$and -45^o)are minimized.

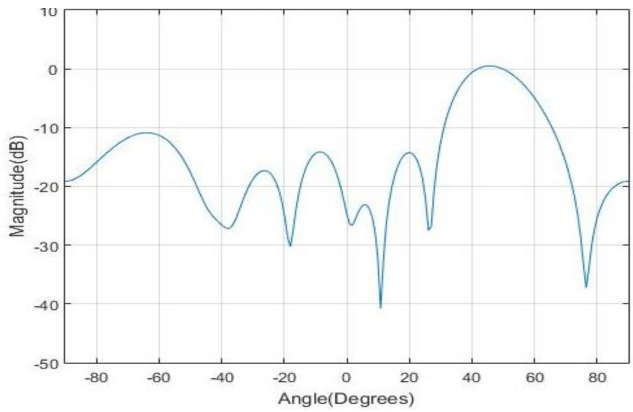

Figure 2. Intelligent Antenna Beam-forming

The power reduction δ is plotted as a function of the gain obtained using intelligent antenna system in base station as shown in Figure 3. In a 50% loaded system, an array of two antenna elements could lead to 4.77 dB power reduction.

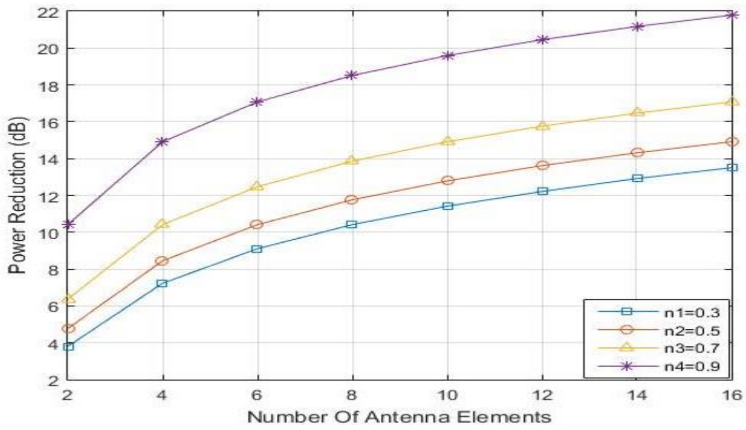

Figure 3. Power Reduction With Intelligent Antenna.

Equations 9 and 10 are plotted in Figure 4. It can be concluded the up-link power will be reduced by a factor of M^{-1}, and the down-link power will be reduced by a factor of M^{-2}, reducing the base station amplifier output power. Eight antenna elements can reduce the total transmitted power by 9.03dB, and the amplifier output power by 18.06 dB. The mobile phone transmit power can be reduced as the intelligent antenna base station is able to receive a weaker signal, and this results in mobile phone battery life extension as shown in Figure 5 at which the battery life is plotted as a function of the cell phone output (transmitted power). When the cell phone output power is 300mW the battery can be used for 25 hours and this period will be doubled during the usage of intelligent antenna in base stations.

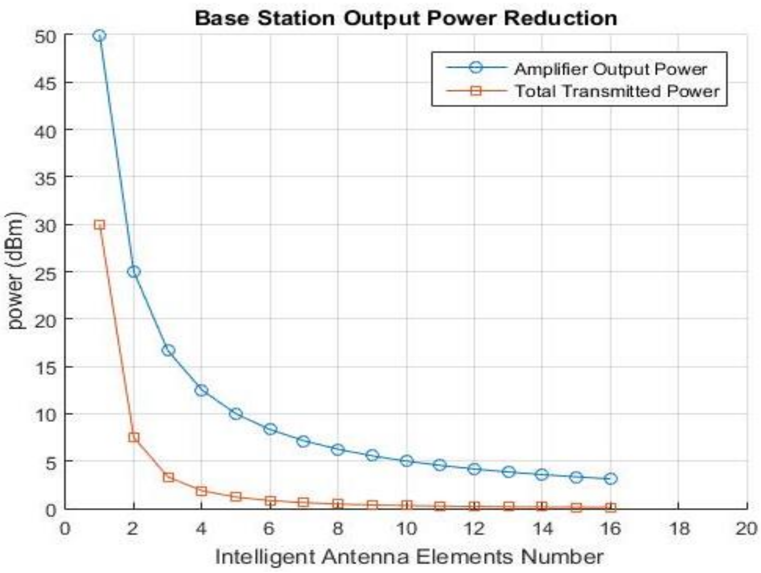

Figure 4. Power Reduction in Base Station Amplifier

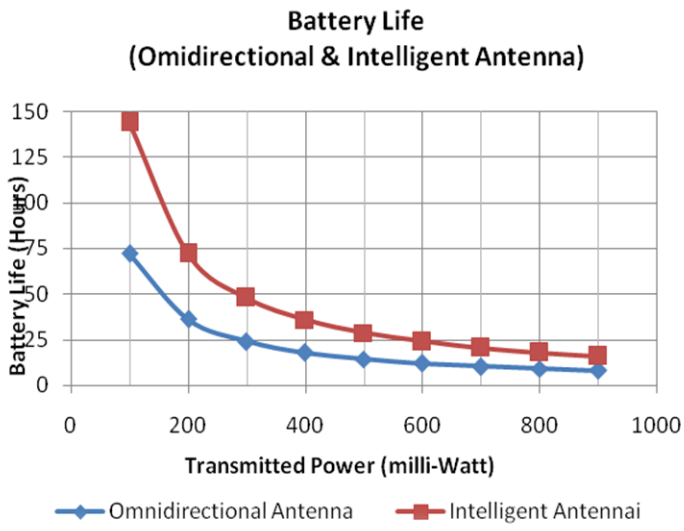

Figure 5. Battery Life at different Output Powers.

The required number of base station will be reduced by $(1/M)$, and this in turn will reduce the number of electromagnetic radiation sources, and the environment pollution.

5. Conclusions

The rapid growth in transmitted data volume through cellular communication networks results in ever increasing energy costs and network design complexity. Intelligent antenna systems offer good potential to minimize power consumption due to their potentials to optimize reception and maximize signal to interference ratio concentrating the energy transmission towards the desired user.

It has been noticed that gain obtained during using these antennas leads to reduce the amplifier output can be reduced by 20 log M, and reduce the required base stations by a factor (1/M). This in turn can reduce power consumption in the cell phone units, and reduce the electromagnetic pollution to harmless levels.

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