Range-Coverage Extension Using Smart Antennas in Mobile Communications Systems

Adheed H. Sallomi [1]
Sana R. Salim [2]

[1]*Department of Electrical Engineering, College of Engineering, Al-Mustansiriyah University, Baghdad, Iraq*
adalameed@yahoo.com
[2]*Department of Physics, College of Sciences, Al-Mustansiriyah University, Baghdad, Iraq*

The growing demand for wireless communications services is constantly increasing the need for better coverage and quality service. Smart antennas employ collection of individual elements in the form of an array, so, they give rise to narrow beam with increased gain when compared to conventional antennas using the same power. The array gain is the average increase in signal power at the receiver due to a combination of the signals received at all antenna elements. The gain provided by adaptive antenna array is proved to provide an extension in a communication range that depends on the number of array elements. The simulation had done by using power exponent radio wave propagation model shows that the gain provided by smart antennas can extend the range of a cell to cover a larger area and more users than would be possible with omnidirectional or sector antennas. The increase in gain leads to employ fewer base stations to cover a given area.

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1. Introduction

The wireless (cellular) technology is partially replacing the use of the wired telephone network. Cellular systems accommodate a large number of mobile units over a large area within a limited frequency spectrum.

A cellular network consists of a large number of wireless subscribers who have cellular telephones (users) that can be used in cars, in buildings, or almost anywhere. There are also a number of fixed base stations, arranged to provide coverage of the subscribers [1]. The unit area of RF coverage for cellular is called a cell. In each cell, a base station transmits from a fixed cell site location, which is often centrally located in the cell, to mobile stations. Base stations are supported by, and interconnected to each other and the public switched telephone network (PSTN) via mobile switching center (MSC), as illustrated in Fig. (1) [2-3].

The coverage area is simply the area in which communication between a mobile and the base station is possible. Range extension is a means of increasing coverage area [1]. The channels used for transmission from the base station to the mobiles are called forward or downlink channels, and the channels used for transmission from the mobiles to the base station are called reverse or uplink channels [4].

2. Smart Antenna Systems

Each base station has towers that support several transmitting and receiving antennas. Omni-directional or sectored antennas used in base stations of mobile communication systems, can be considered as an inefficient use of power as most of it has been radiated in other directions than toward the user as shown in Fig. (2) [1]. Besides, other users can experience interference from this “stray” radiated power [5].

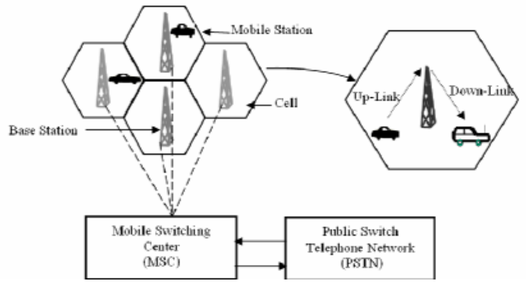

Fig. (1) Basic cellular communication system 2-smart antenna systems

The idea of smart antennas is to direct a single beam to each user to optimize the radio performance and to increase the communication system range as shown in Fig. (2). Smart antennas consist of an array of antenna elements and a smart processing of antenna signals. The goal of smart antenna is to receive in the uplink as much power as possible from the desired

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mobile station. In the downlink as much power as possible has to be transmitted into the direction of the desired mobile station [6-7] .

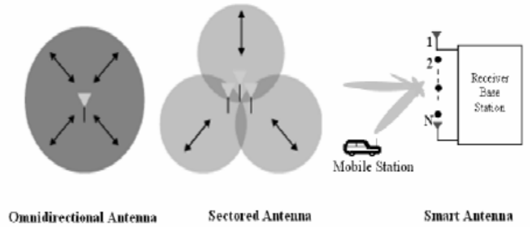

Fig. (2) Base station antennas [3]

During using smart (adaptive) antenna array of M elements the signal amplitude increases (M) times because the desired signal received at each antenna element is phase-shifted due to weight coefficient, and then the signal components from each element are positively combined [8-9].

The gain provided by smart antennas can extend the range of a cell to cover a larger area and more users than would be possible with omnidirectional or sector antennas [11]. The interference-rejection capability of the smart antenna system provides significanlly more coverage than either omnidirectional, or sectorised antennas as it can direct its beam in the direction of the user of interest [12].

3. Power Exponent Radio Wave Propagation Model

In planning cell coverage area the goal is to estimate the electric field strength of the transmitted signal at the receiver end (perimeter of coverage area) [11].

Friis transmission equation relates the power received to the power transmitted between two antennas separated by distance large enough for each antenna to be in the far field region of the other. This equation is given as,

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 .G_t G_r \qquad (1)$$

The power exponent model is also used to predict the power transfer between a transmitter and a receiver in different environments. The received power (P_r) at distance (d) from the transmitting antenna can be expressed with respect to the power measured at a certain standard distance (d_o), i.e. the reference power ($P_r(d_o)$) [8].

$$P_r(d) = P_r(d_o).\left(\frac{d_o}{d}\right)^{\gamma} \quad for \quad d > d_o \qquad (2)$$

where (d_o) is a reference distance, that is chosen to be in the far-field of the antenna, and considered to be close enough to the transmitter such that multipath and diffraction are negligible. This model takes into account the decrease in energy density suffered by the radio wave due to spreading, as well as the energy loss due to the interaction of the wave with the propagation environment. The signal loss (L_P) at distance (d) from the transmitting antenna can be expressed as:

$$L_p(d) = L_p(d_o).\left(\frac{d_1}{d_o}\right)^{\gamma} \quad for \quad d > d_o \qquad (3)$$

The value of (γ) depends on specific features of the propagation environment and it is between (2) and (5). Larger values of (γ) correspond to more obstruction and hence faster decrease in average received power as distance become larger [1].

4. Coverage Extension during Using Smart Antennas

We used the power exponent model to derive the approximate relationship of coverage area to antenna gain (G).

The array gain (G) is the average increase in signal power at the receiver due to combination of the signals received at all antenna elements. It is proportional to the number of antennas. For an array of M antenna elements, the resultant beam gain is:

$$(Array\ Gain)_{dB} = G = 10\log_{10} M \qquad (4)$$

If for a single antenna the highest permissible attenuation level (path losses) is achieved at the distance (d_1) from the base station, then after application of smart (adaptive) antenna array the same attenuation is achieved at the distance (d_2), where

$$L_p(d_2) = L_p(d_1) + G \qquad (5)$$

$$L_p(d_o) + 10\ \log\left(\frac{d_2}{d_o}\right)^{\gamma}$$

$$= L_p(d_o) + 10\ \log\left(\frac{d_1}{d_o}\right)^{\gamma} + G \qquad (6)$$

$$G = 10\ \log\left(\frac{d_2}{d_o}\right)^{\gamma} - 10\ \log\left(\frac{d_1}{d_o}\right)^{\gamma} \qquad (7)$$

$$G = 10\ \log\left(\frac{d_2}{d_o}.\frac{d_o}{d_1}\right)^{\gamma} = \log\left(\frac{d_2}{d_1}\right)^{10\gamma} \qquad (8)$$

From the logarithm definition and assuming that the value of (γ) is equal to (4) for urban environment, we can write:

$$10^G = \left(\frac{d_2}{d_1}\right)^{40} \qquad (9)$$

$$10^{\frac{G}{40}} = \left(\frac{d_2}{d_1}\right) = Range\ Extension\ Factor = \rho \qquad (10)$$

$$\log \rho = 0.25 \log M = \log M^{0.25} \qquad (11)$$

The additional gain results in extending the range (area) of the cell.

$$\rho = \frac{d_2}{d_1} = M^{0.25} \qquad (12)$$

$$\because A_2 = A_{smart} = \pi.(d_2)^2$$
$$and\ .A_1 = A_{omni} = \pi.(d_1)^2 \quad (13)$$

$$\left(\frac{A_2}{A_1}\right) = \left(\frac{d_2}{d_1}\right)^2 = \left(M^{0.25}\right)^2 \quad (14)$$

$$\left(\frac{A_2}{A_1}\right) = M^{0.5} = \sqrt{M} \quad (15)$$

Range extension is suited to rural areas, where the user density is low and it is desirable to cover as much area with as few base stations as possible [11].

5. Base Station Reduction

The additional coverage of a base station means that an operator can achieve a substantial reduction in infrastructure costs, due to the reduction in required base stations.

Assuming that the base stations are distributed uniformly in a considered area (A), then to increase the cell radius from (d_1) (the area of a single cell is (A_1) to (d_2) (the cell area is now (A_2), the necessary base stations decrease according to the reduction factor (g) which is given by:

$$g = \frac{A/A_2}{A/A_1} = \frac{A_1}{A_2} = \frac{\pi.(d_1)^2}{\pi.(d_2)^2} = \frac{(d_1)^2}{(d_2)^2} = \left(\frac{1}{\rho}\right)^2 \quad (16)$$

$$\rho = M^{0.25} \quad (17)$$

$$g = M^{-0.5} \quad (18)$$

Fig. (3), shows the range-coverage extension factor against the number of smart antenna elements. Fig. (4), shows the base stations reduction factor against the number of smart antenna elements. It can be seen that using eight elements smart antenna can reduce the number of base station by a factor of 35%.

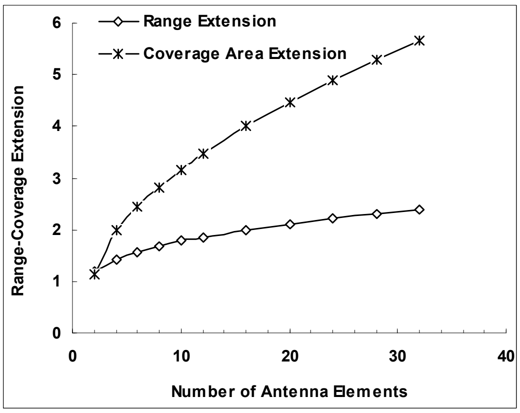

Fig. (3) Number of array elements and range-coverage extension

6. Simulation of Coverage Extension by Smart Antennas

The power exponent model has been used to simulate the benefits achieved during using smart antenna of eight elements (M=8), in a base station of a mobile communication system. For this simulation, the reference distance (d_o) is set to be 720m and the transmitted power is set to be 0.6 watt (27.78dBm) in up-link.

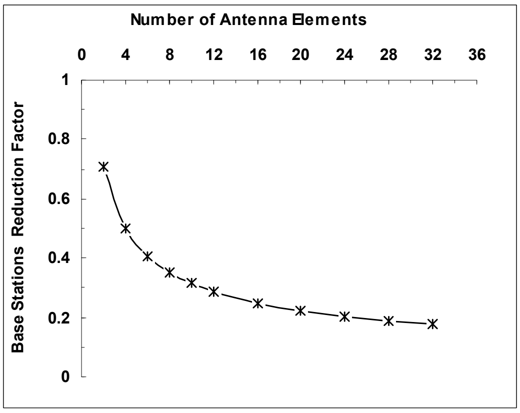

Fig. (4) Number of array elements and base station reduction factor

Fig. (5), shows that when a subscriber unit transmits 0.6W (27.78dBm), the power received at a base station located 2km away from the mobile unit will receive (-78.638dBm), during using omnidirectional antenna, while it will equal to (-69.608dBm), when array of eight elements used at the base station. The difference is due to the gain obtained by using the array (10log(8)). The gain obtained in smart antenna allows base station to transmit lower power, resulting in overall electrical power cost saving.

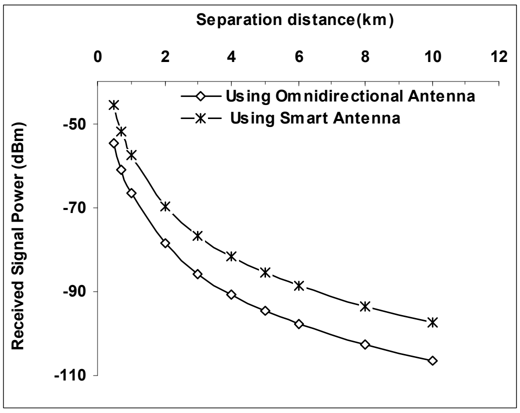

Fig. (5) The received signal power using omnidirectional and smart antenna

The plot of maximum separation distance (range) against the transmitted power is shown in Fig. (6). It can be noticed that when the transmitted power is 1W the maximum separation distance is 5.5km during using omnidirectional antenna while it is 9.25km when a smart antenna of eight elements is used. The maximum separation distance increases by a factor of 68% during using smart antenna. This means that base stations can be placed

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further apart leading to a more cost-efficient development.

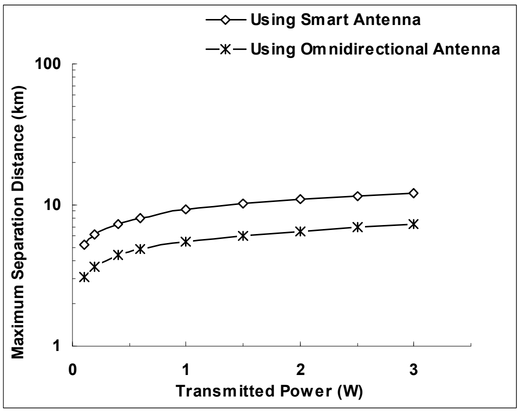

Fig. (6) The maximum separation distance in urban environments using omnidirectional and smart antenna

7. Conclusion

The smart antenna gain compared to a single element antenna can be increased by an amount equal to the number of array elements. Because smart antennas is more directive than sector or omnidirectional antennas, it can provid an additional gain , so it can extend the range of a cell to cover an area that is larger by $(\sqrt{M})$ than would be possible with omnidirectional or sector antennas.

Using smart antenna arrays reduces the number of base station required for a mobile system by amount of $(1/\sqrt{M})$. Using antenna arrays with M elements, for mobile communication systems will help in producing better quality beam patterns in terms of directivity and coverage.

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