Increasing Capacity of Users Through The Use Of Smart Base Station Antenna as SDMA System.

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Abstract

A smart antenna system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. Among the most sophisticated utilizations of smart antenna technology is SDMA, this technology increases the number of users that can access an existing wireless phone system by exploiting the spatial characteristics of the channel itself through highly developed implementation of an intelligent antenna system's capabilities for receiving and transmitting .The cellular system must evolve to provide the required coverage and capacity, increasing the capacity of a cellular system using adaptive base station antennas by finding the optimum tradeoff between SDMA and interference rejection approaches. Measurements presented in Mat lab application have implications for increasing capacity and coverage area through the use smart antenna with SDMA when we compare the results with Omni antenna under the same number of channels, , area, number of cells per cluster.

Keywords: Smart antennas, SDMA, Capacity, Omni antenna.

زيادة السعة لأعداد المستخدمين من خلال استخدام محطة الهوائيات الذكية مع التقسيم المضاعف الفضائي.

الخلاصة

منظومة الهوائيات الذكية تستطيع العمل بصورة ذاتية لتغيير الاتجاه وفقا لسلوك الاشارة في بيئتها المحيطة وهذا يؤدي ايضا لزيادة صفات الاداء(السعة مثلا) للأنظمة اللاسلكية. بالرغم من التقنيات المعقدة التي تستخدم الى جانب الهوائيات الذكية فأن نظام التقسيم المضاعف الفضائي هو الانسب لمجاراة الزيادة في اعداد المستخدمين للأنظمة الخلوية عن طريق الاستغلال الامثل لصفات القنوات الفضائية والتي تتطلب تأمين مناسب لمجال التغطية والسعة ان ذلك يحتاج الى طريقة مثلى لتوظيف هذا النظام مع مراعاة عدم حدوث عمليات تشويه سلبية لأداء العمل. وفق المعادلات الحسابية الخاصة بتحديد السعة ومناطق التغطية، تم محاكاتها بتطبيق برنامج (ماتلاب) لمنظومة الهوائيات الذكية والمتعددة الاتجاهات تحت نفس العدد من القنوات وعدد الخلايا ومساحة التغطية ليمكننا

ذلك بمقارنة النتائج حيث تبين تفوق وزيادة الخاصية السعوية ومنطقة التغطية للنظام الذي يستخدم الهوائيات الذكية.

1. Introduction.

Smart antennas provide a means of strengthening desired signals and suppressing unwanted signals at a radio receiver using an array of two or more antennas as elements of the array through spatial filtering, often called beam forming. The overall purpose of using a smart antenna array in a wireless system is to improve the ability of a wireless system to efficiently convey error-free information over a radio channel and to increase the capacity of the system.

Mobile radio communication systems are currently characterized by an ever-growing number of users which is coupled with limited available resources in particular in terms of usable frequency spectrum. Adaptive antennas can increase the coverage area and or the capacity of a wireless communication system. The coverage, or coverage area, is simply the area in which communication between a mobile and the base station is possible. The capacity is a measure of the number of users a system can support in a given area. Three strategies that employ smart antennas are usually considered [1] Range extension (a means of increasing coverage area), interference reduction Fig.(1) ,and spatial division multiple access (SDMA) which increases the capacity of a system.

In many system, mobile stations communicate through a base station which is attached to wired network, here the capacity of a set of portable stations sharing a single indoor radio channel[2].

In SDMA a number of users share the same available resources and are distinguished only in the spatial dimension, here some error performance analysis to increase capacity using SDMA technique, which based on deriving and exploiting information on the spatial position of mobile terminals[3].

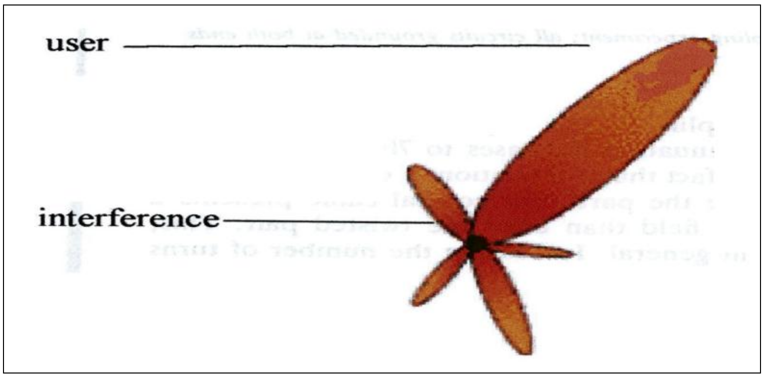

Fig.(1) Adaptive Array Coverage

2. Coverage area & Capacity.

The gain provided by adaptive 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 coverage area is the area of useful communications around a base station antenna. In a homogeneous propagation environment the maximum transmit-receive range is the same in all azimuthally directions and the coverage area is given by:

$$A_c = \pi R^2 \quad \text{.......(1)}$$

where A_c is me coverage area of the cell and R is the maximum transmit-receive range. Of course, this is only a rough approximation of the situation in a real environment, in which terrain, buildings, vegetation, etc. affect propagation. The approximate relationship of coverage area to antenna gain can be derived using a simple exponential path loss model. In this model, the power at a receiver, P_r is given
by:

$$P_r = P_t G_t G_r PL_{(d0)} \left(\frac{R}{d0}\right)^{-\gamma} \quad \text{.......(2)}$$

where P_t is the transmitter power, G_t and G_r are the transmit and receive antenna gains, respectively. $PL_{(do)}$ is the free space path loss at some reference distance do from the transmitter (on the order of 1 km for a cellular system), R is the transmit-receive range, in the same units as d_0, and γ is the path loss exponent, which is typically has a value between 3 and 4.This model assumes $R \geq d_0$. Rearranging (2) yields:

$$R = d_0 \left(\frac{P_t G_t G_r PL}{P_r}\right)^{\frac{1}{\gamma}} \quad \text{.......(3)}$$

and hence (1), coverage area varies with antenna gain as:

$A_r \propto G^{\frac{2}{\gamma}}$

where G is either transmit or receive antenna gain, and provided thus the gain of the other antenna is held constant. The following equation shows how coverage can be increased by using a base station antenna with switched directional beams because its gain is larger [4].

$$A_{c,smart} = A_{c,omni} \left(\frac{G_{smart}}{G_{omni}}\right)^{\frac{2}{\gamma}} \quad \text{.......(4)}$$

The capacity is defined as a measure of the number of users a system can support in a given area. It is related to the spectral efficiency of a system, as well as the amount of traffic offered by each user. The spectral efficiency E, measured in channels/km2/MHz, is expressed as:

$$E = \frac{B_t/B_{ch}}{B_t N_c A_c} = \frac{1}{B_{ch} N_c A_c} \qquad (5)$$

where B_t is the total bandwidth of the system available for voice channels (transmit or receive), in MHz, B_{ch} is the bandwidth per voice channel in MHz , N_c is the number of cells per cluster, and A, is the area per cell in square kilometers[5]. The capacity of a system is measured in channels/km^2 and is given by:

$$C_{omni} = EB_t = \frac{B_t}{B_{ch} N_c A_c} = \frac{N_{ch}}{N_c A_c} \qquad (6)$$

Where $N_{ch} = B_t / B_{ch}$ is the total number of available transmit or receive voice channels in the system. actual number of users that can be supported can be calculated based on the traffic offered by each user and the number of channels per cell. From (6),it is evident that capacity can be increased in several ways , these include increasing the total bandwidth allocated to the system, reducing the bandwidth of a channel through efficient modulation, decreasing the number of cells in a cluster, and reducing the area of a cell through cell splitting. If somehow more than one user can be supported per RF channel, this will also increase capacity.

3. Spatial Division Multiple Access (SDMA).

Adaptive antennas allows a base station to communicate with two or more mobiles on the same frequency using space division multiple access (SDMA). In spatial division multiple access (SDMA), multiple mobiles can communicate with a single base station on the same frequency. By using highly directional beams and/or forming nulls in the directions of all but one of the mobiles on a frequency, the base station creates multiple channels using the same frequency , but separated in space. This approach is shown in Fig.(2)[6].

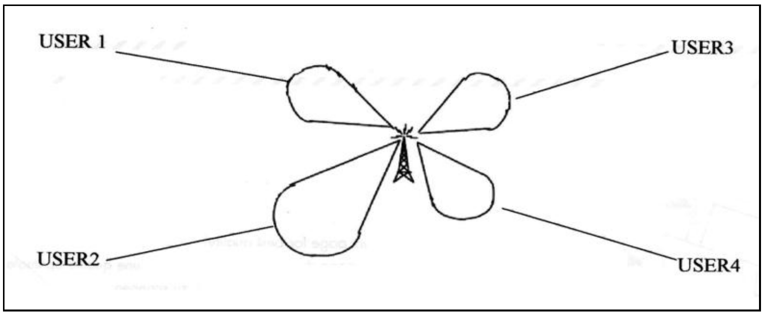

Fig.(2) Spatial division multiple access (SDMA) using adaptive antennas.

In traditional cellular systems the base station, having no information on the position of mobile units, and hence it is forced to radiate the signal in all direction, in order to cover the entire area of the cell. This entails both a waste of power and the transmission, in the directions where there are no mobile terminals to reach, of a signal which will be seen as interfering for co-channel cells, i.e. those cells using the same group of radio channels. Analogously, in reception, the antenna picks up signals coming from all directions, including noise and interference. These considerations have led to the development of the SDMA technique, which is based on deriving and exploiting information on the spatial position of mobile terminals. In particular, the radiation pattern of the base station, both in transmission and reception, is adapted to each different user so as to obtain, as shown in Fig.(3), the highest gain in the direction of the mobile user. Simultaneously, radiation nulls shall be positioned in the directions of interfering mobile units[7].

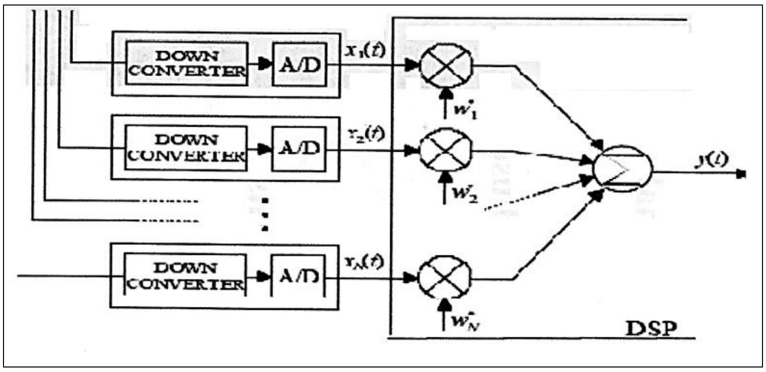

Fig.(3). Block diagram of Adaptive array systems.

This system thus comprises an array of antennas and a Digital Signal Processor (DSP) tasked with real time processing of signals received or to be sent to the different antennas. With reference to Fig.(3), it can be observed that the RF signal received by each of the N antennas comprising the array is at first brought down to base band and then converted into digital form. The N complex signals obtained are then sent as inputs to the DSP, which multiplies the signal of each antenna by a suitable factor W_i^*, and finally adds the various terms. The output signal is therefore given by:

$$Y(t) = \sum_{i=1}^{N} W_i^* X_i(t) \qquad (7)$$

An appropriate choice of the weights vector w = [wl, w2, ...wN] allows to give the radiation pattern the desired characteristics. In particular, vector w is determined using an adaptive strategy. Coefficients are therefore updated periodically, based on the observation of data received. To assure correct operation of the system, it is necessary that the adaption rate could compensate the environmental variations, due to the mobility of the sources and accentuated by the presence of multiple paths. The use of an adaptive antenna array at the base station thus allows to introduce the SDMA technique, whose main advantage is the capability to increase system capacity, this mean that the number of users it can handle.

In conventional access techniques, orthogonally between signals associated with different users is obtained by transmitting them in different frequency bands (FDMA) in different time slots (TDMA) or using different code sequences (CDMA). Using an antenna array, it is possible to create an additional degree of orthogonally between signals transmitted to and from different directions. It is thus possible to assign the same physical channel to several mobile units, when the angles at which they are seen by the base station are sufficiently separated[8]. The result is an increase in the number of available channels, since the same physical channel, for example the same carrier in a FDMA system or the same time slot in a TDMA system, can be subdivided into multiple spatial channels, each of which is assigned to a different user. It must be noted that the term "SDMA" refers, strictly speaking, only to the latter application, in which a space division multiple access is actually accomplished. With the CDMA technique, since all mobile units share the same band, the number of potential interfering units is very high, certainly higher than the number of antennas in the array, i.e. the number of degrees of freedom of the adaptive system. Interfering units can also be considered uniformly distributed around the base station[9].

If SDMA can be achieved , the spectral efficiency can be increased dramatically in an SDMA system the spectral efficiency becomes:

$$E = \frac{N_{sdma}}{N_c A_c B_{ch}} \qquad (8)$$

A pseudo-SDMA approach combining adaptive antennas with CDMA is considered. In this approach, steerable directional antennas are shown to increase the capacity of a cellular system[10].

In addition to the opportunity to increase system capacity, the SDMA technique has additional characteristics making its introduction in a mobile radio system advantageous, In particular, it is possible to exploit the higher receive gain offered by an antenna array with respect to an omnidirectional case, to allow mobile units to transmit at reduced power, and therefore lower consumption. At equal power, gain can be exploited to extend cell size. This is useful when it is necessary to cover vast surface areas (typically rural areas)[11], characterized by a low mobile radio traffic density, with a limited number of base stations.

4. Matlab works & results.

In Matlab works can be used the equations for the C_{omni} & C_{sdma} of smart antenna with same number of N_{ch}, Ac, and N_c (N_{ch} = 50-300 number of available transmit or receive voice channels, A_c= 50 area in square kilometers, N_c=7 cells per cluster) to compare the results of works and prove that the capacity of coverage area is increasing in a smart antenna with SDMA more than Omni antenna (Fig.4, Fig.5 and Table. l). The curve of the Matlab works application (Fig6) by an exponential path loss model (γ= 3.5) prove that the cover area for smart antenna (A_{smart}) is larger than omni antenna (A_{omni}) ,this mean that the range extension is best 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. If the user density is high, simply expanding the coverage area will result in a cell containing more users than the base station can serve with its limited number of channels.

The simulation results emphasize that dynamic inter-cellular channel allocation combined with SDMA can further increase the capacity as compared to Omni antenna and thus can enhance the efficiency of frequency usage.

Table. 1. summary capacity for each Omni antenna& smart antenna from Matlab.

number of channels(N_{ch})	capacity(channels/km^2) of an Omni antenna	capacity(channels/km^2) of a smart antenna
50	0.1428	0.2857
100	0.2857	0.5714
150	0.4285	0.8571
200	0.5714	1.1428
250	0.7142	1.4285
300	0.8571	1.7142

Below the curves in Matlab works [Fig.(4), Fig.(5) & Fig(6)].

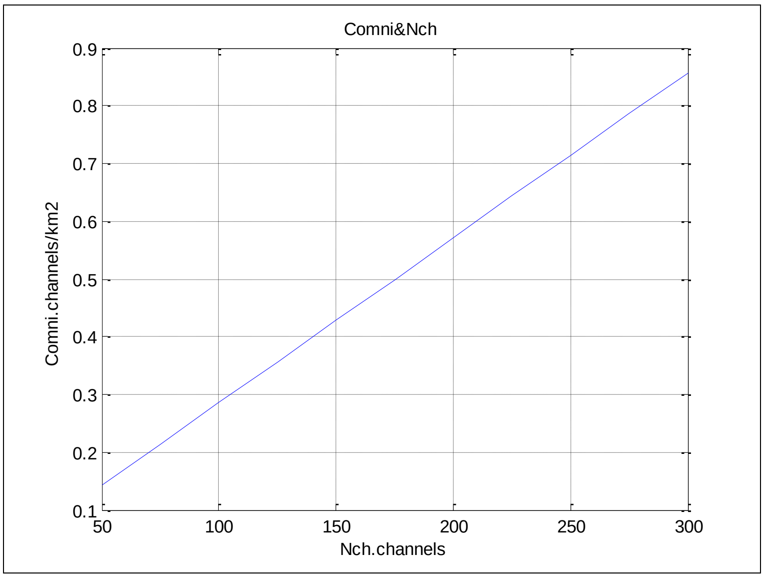

Fig.(4a) The capacity of an Omni antenna.

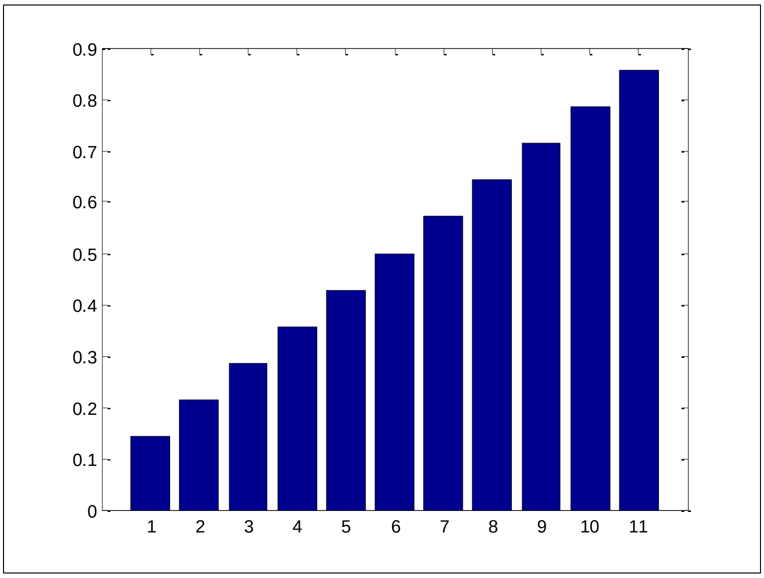

Fig.(4b) The bar graph of capacity for an Omni antenna .

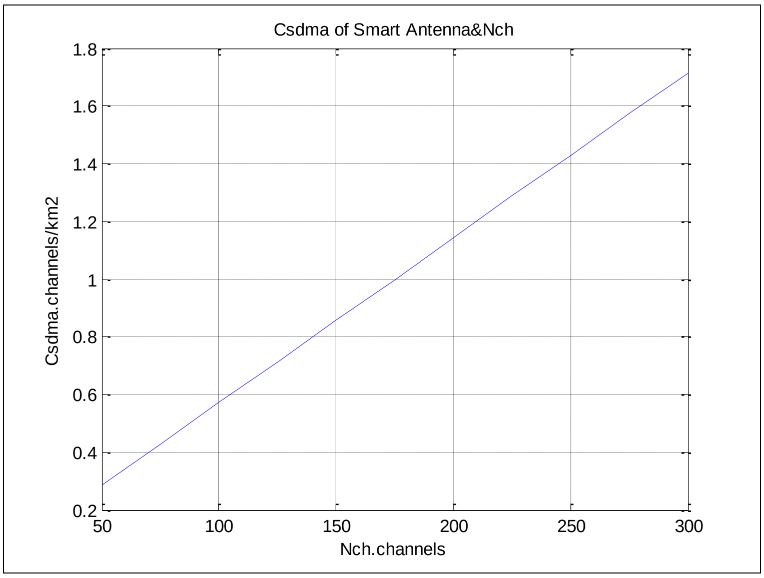

Fig.(5a) The capacity of a smart antenna .

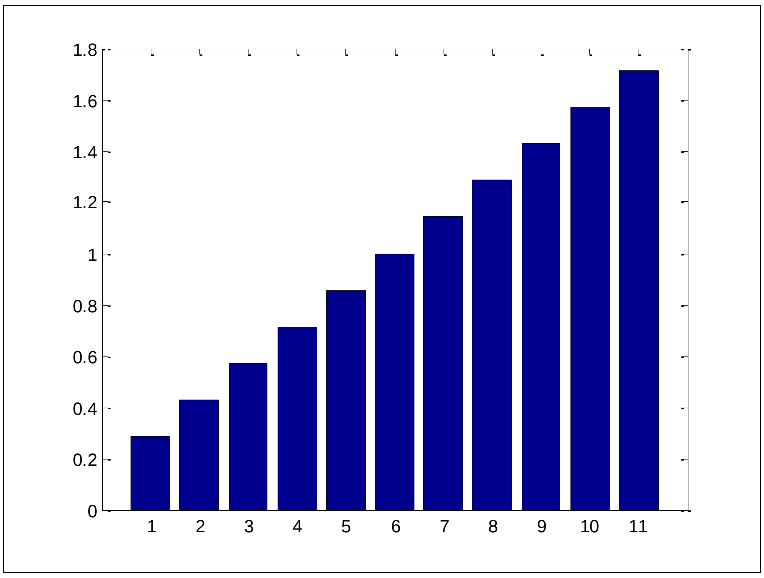

Fig.(5b) The bar graph of capacity for a smart antenna.

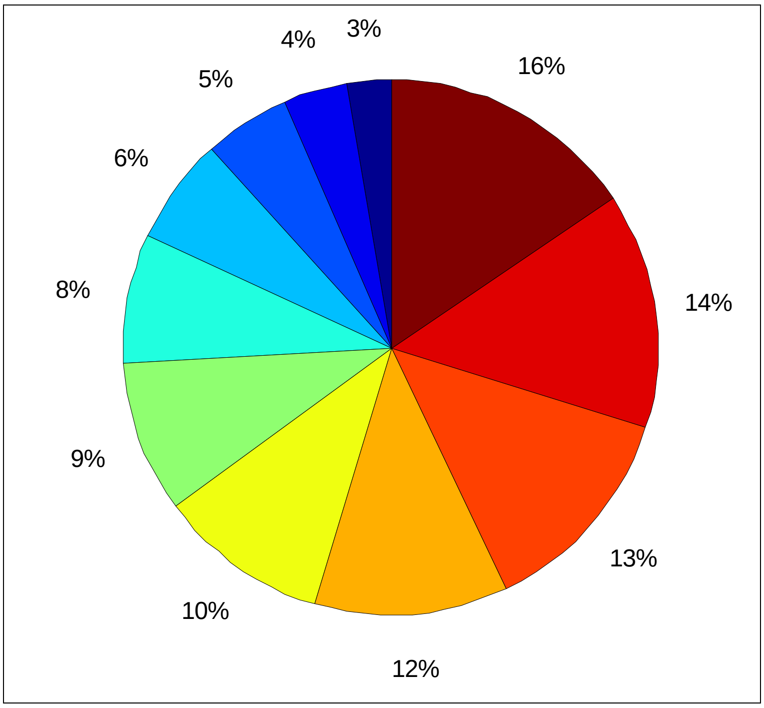

Fig.(5c) The pie graph is same for each Omni antenna& smart antenna.

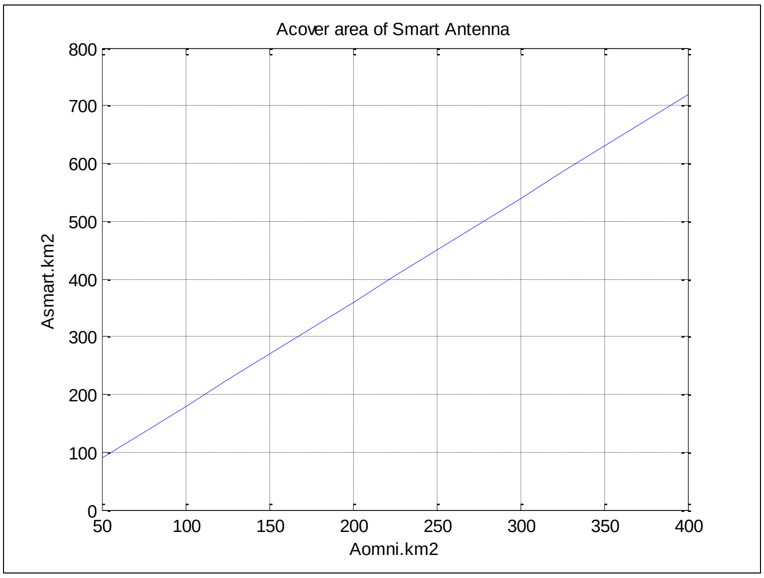

Fig.(6) The cover area of smart & Omni antenna with path loss model (γ=3.5).

5. Conclusions.

The Space Division Multiple Access (SDMA) technique is compatible with almost any modulation method, bandwidth, or frequency band ,it can be integrated with conventional access techniques, such as FDMA, TDMA and CDMA; and can be implemented with a broad range of array geometries and antenna types such as smart antenna, therefore it can be used in all the mobile systems. It allows smart antennas offer several advantages over omnidirectional antennas, these include increased coverage through range extension and increased capacity. The dual purpose of a smart antenna system is to augment the signal quality of the radio-based system through more focused transmission of communications systems.

List of symbols:

Ac	The cover area in square kilometers.
C	The capacity of a system is measured in (channels/km^2).
CDMA	Code division multiple access.
DSP	Digital signal processors.
DOA	Direction of arrival.
dB	Decibel.
E	The spectral efficiency, measured in channels(km^2/MHz).
FDMA	Frequency Division Multiple Access.
N_{ch}	Total number of available transmit or receive voice channels.
N_{sdma}	The average number of simultaneous spatial channels per RF channel.
Nc	The number of cells per cluster.
G	Transmit or receive antenna gain.
TDMA	Time division multiple access.
SDMA	Space division multiple access

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