ADAPTIVE ANTENNAS

WHY ADAPTIVE (SMART) ANTENNAS?

1-Why are smart antenna (SA) and adaptive antennas (AA) emerging now?

- *The concept of smart antennas has been around since the late 50s [1–3]*
- *AA systems capabilities where limited because adaptive algorithms were usually implemented in analog hardware*
- *The technology required to make the necessary rapid and computationally intense calculations has only emerged recently*
- *ADCs, which have high resolutions and sampling rates up to 100 GSa/s [4] makes the direct digitization of most radio frequency (RF) signals possible in many wireless applications*
- *In addition, DSP can be implemented with high speed parallel processing using field programmable gate arrays (FPGA)*
- *The global demand for all forms of wireless communication and sensing continues to grow at a rapid rate, SA(or AA ;where an adaptive algorithms are involved) are the practical realization of the array signal processing and have a wide range of interesting applications:*

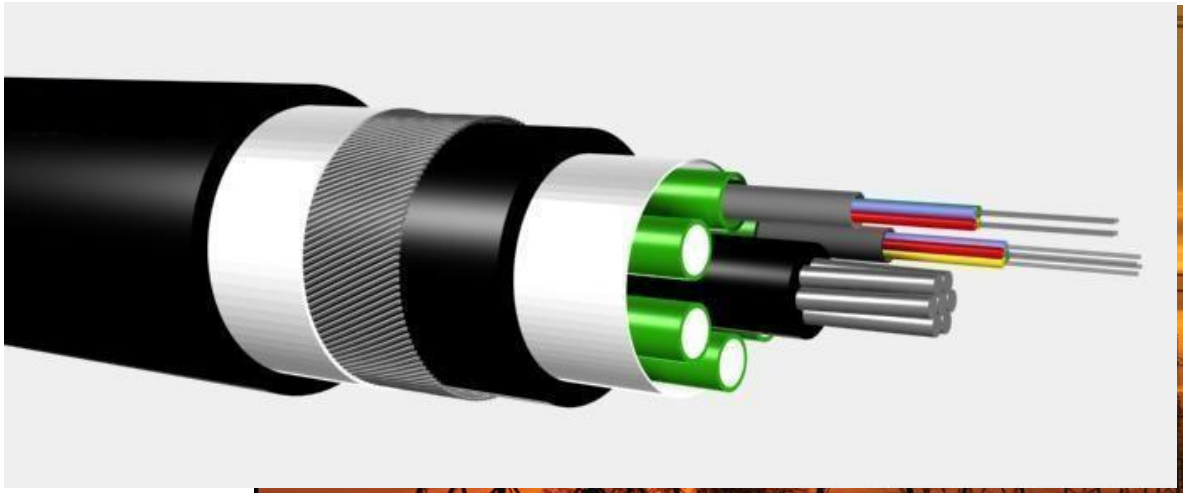
Mobile wireless communications [5] -Software-defined radio [6, 7]-WLAN [8]- Wireless local loops (WLL) [9]-Mobile Internet-Wireless metropolitan area networks (WMAN) [10]-Satellitebased personal communications services-radar [11,12]- Remote sensing-Mobile ad hoc networks (MANET) [13]-High data rate communications [14]- Satellite communications [15]-Multiple-in-multiple-out (MIMO) systems [16]-Waveform diversity systems [17]

- *The rapid growth in telecommunications alone is sufficient to justify the incorporation of SA or an AA to enable higher system capacities and data rates*

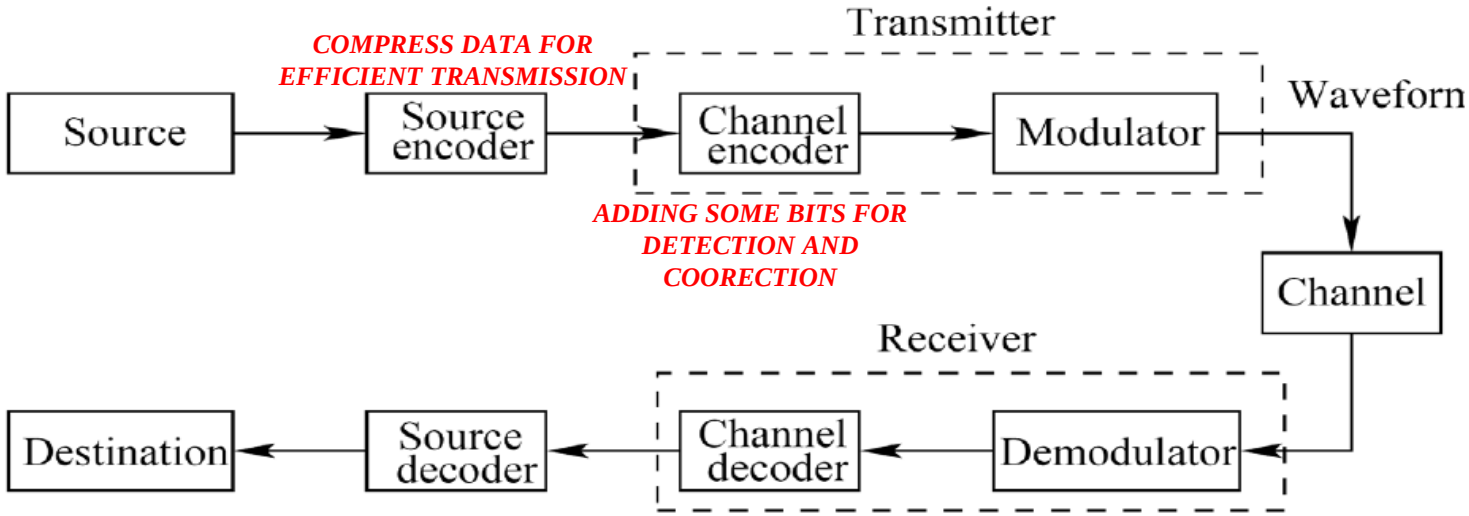
- ***Approach***

- *Transmission over TL are cost effective, more attenuation, more power loss*

- *Transmission over OF are excellent but expensive*



- *Transmission over TL are cost effective, more attenuation, more power loss*
- *Transmission over OF are excellent but expensive*
- *Wireless transmission is the best cost effectiveness*



But it needs

- *Reducing multipath propagation effects*
- *Increasing channel capacity (interference cancellation)*
- *Enhancing S/N*
- *Minimizing power consumption*
- *Efficient spectrum use*
- *Immunity to noise or jamming*

On the other hand there are two main problems in any communication systems:

1-How to acquire more capacity to increase the number of user

at lower cost maintaining the QoS

2-How to obtain greater coverage to decrease the infrastructure and maintenance cost

i.e., the two requirements for the service provider are

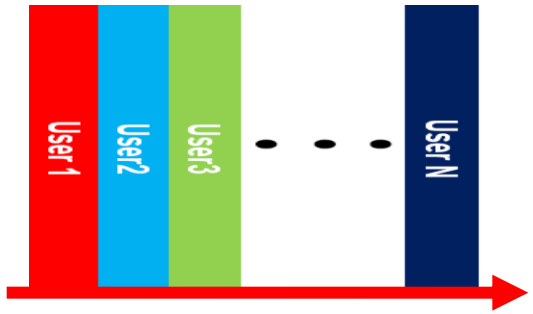
CAPACITY & COVERAGE

which are inversely related

Let us see the multiple access techniques which can achieve

large number of users for the same cost

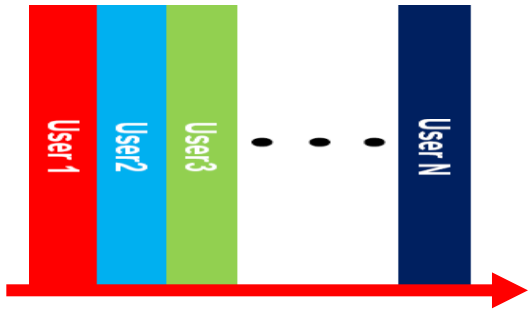
FDMA



A unique frequency slot is assigned to each user for the duration of their call

The number of users within a cell is determined by the number of distinct frequency slots available

TDMA



At the same frequency a user can access the channel at any specific time

Each user is assigned a distinct time slot to access the channel

CDMA

It is a spread spectrum technique, which uses spreading codes to allow the users to transmit simultaneously at the same frequency

Each users signal occupies the entire bandwidth

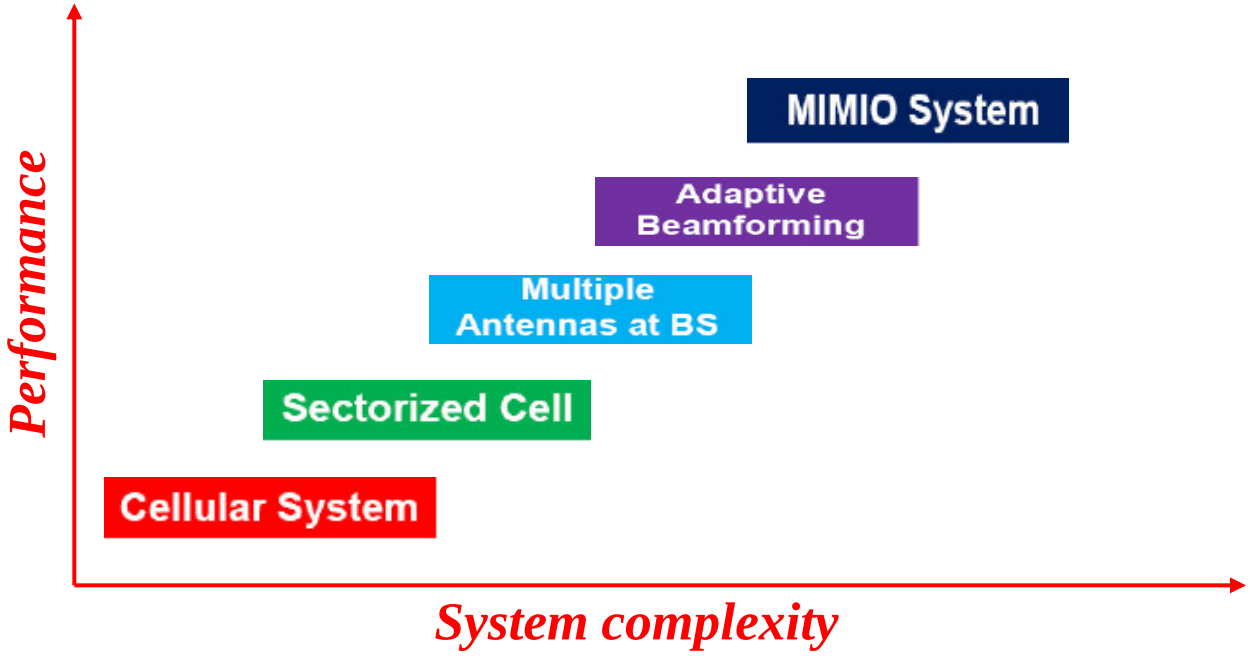
SDMA

"Space domain processing remains as the most promising, if not the last frontier in the evolution of multiple access systems"

Andrew Viterbi

Space diversity is the main idea of adaptive or smart antennas

It allows different users to use the same spatial system resources



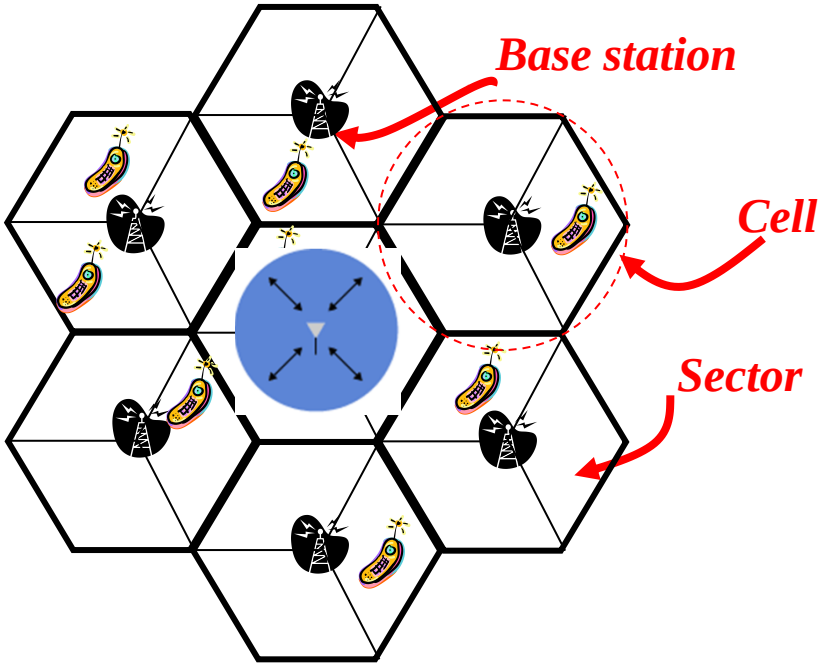
2-Evolution from omni-directional to smart antennas (SA)

(TECHNOLOGY DEVELOPMENT LEVEL) [18]

- To achieve the capacity required for thousands of subscribers for limited number of channels or frequencies, a suitable cellular structure is to be designed

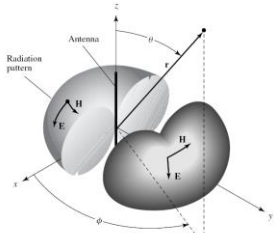
- Cellular networks divide a overage area into multiple cells, each has its own radio infrastructure and users

- At the center of each cell, a base station equipped with an omni-directional antenna with certain bandwidth

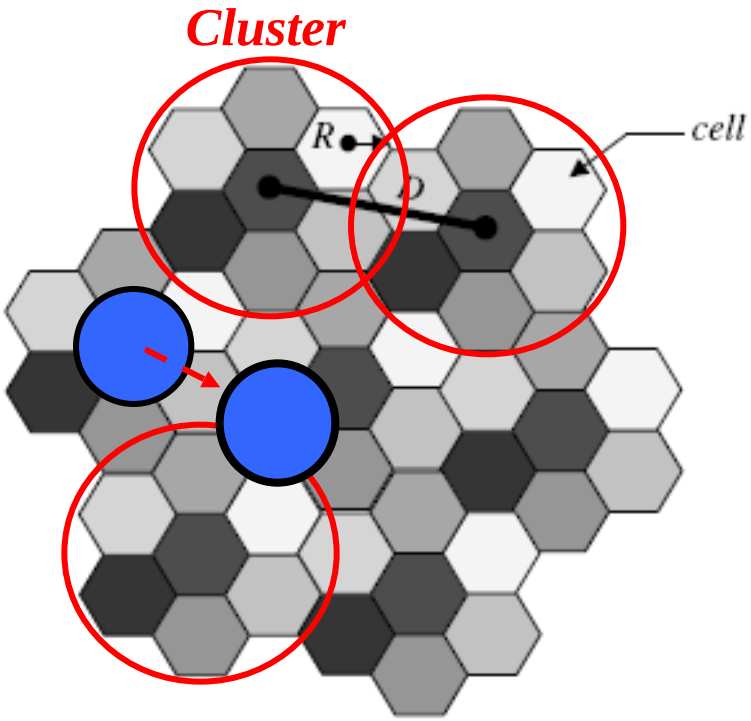


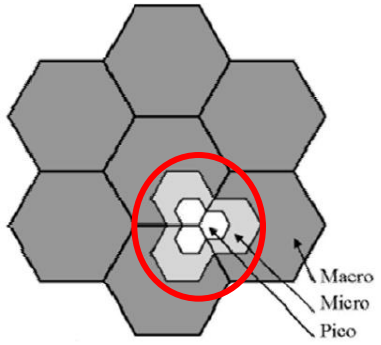
Cellular structure

- *Frequency reused is applied for different cell clusters to increase the number of subscribers*
- *Omni-directional antenna transmits equal intensity in azimuth plane and directive in elevation, hence, only small percentage of the total energy reaches the desired direction*



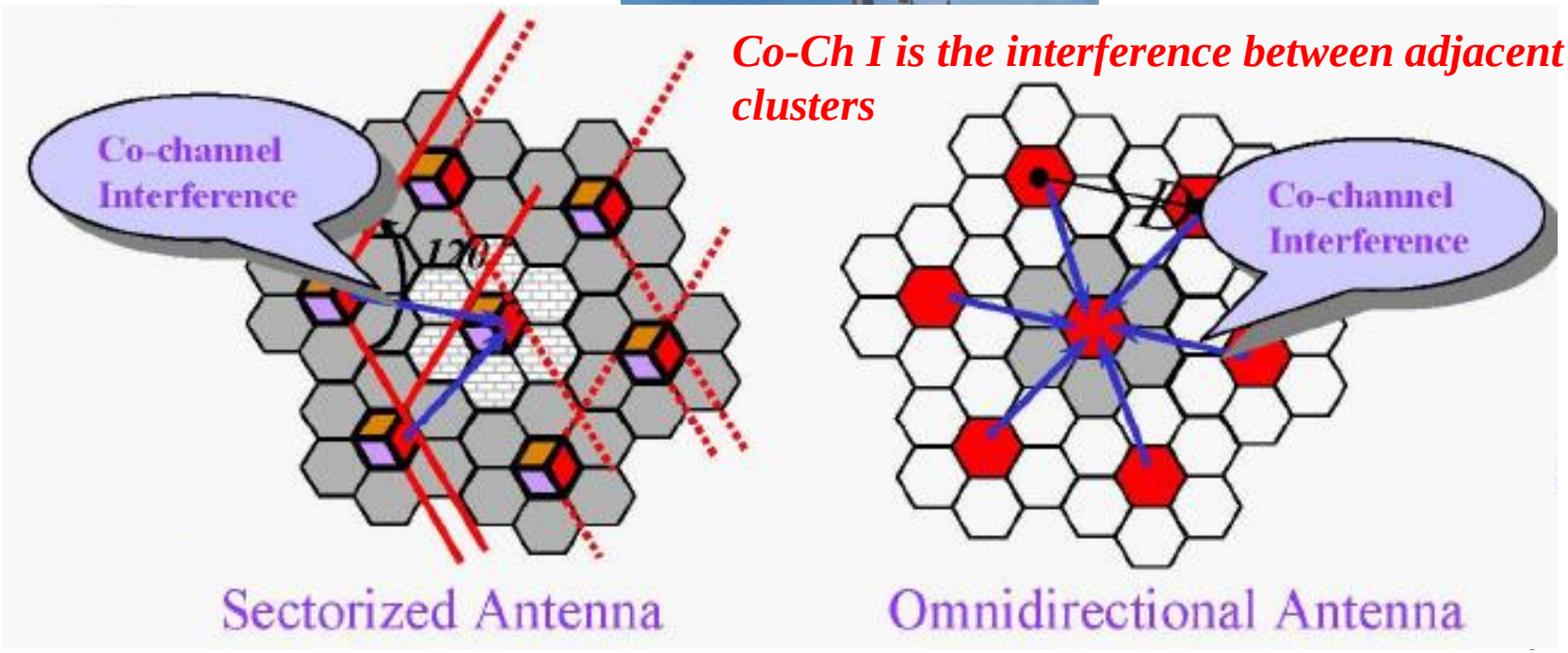
- *As the number of users increases, more interference occurs for those in the same or adjoining cells and hence reducing the capacity*
- *Cell splitting is the immediate solution for this problem. It subdivides a crowded cell into smaller cells called micro cells, each with its own base station and a corresponding reduction in antenna height and transmitting power are achieved*
- *Disadvantages for cell splitting; it's costly due to installing new base stations, increasing the number of handoffs and a higher processing load per subscriber*





- *Sectorization is the solution : antenna system (phased array) are replacing the omni directional antenna. It provides more frequencies for more subscriber per coverage area. This is called the sectoring technique*
- *Typically, a cell is sectorized into three sectors of 120◦ each*
- *It improves signal-to-interference (S/I) ratio and capacity*

Co-Ch I is the interference between adjacent clusters



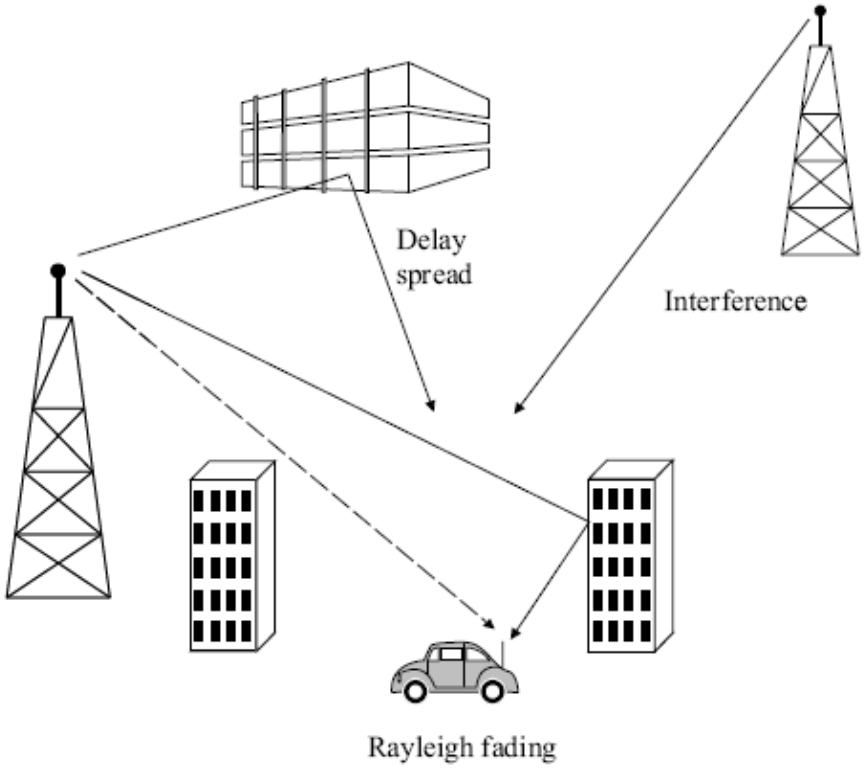
- *The penalty due to channel sectoring at the base station is an increase in the number of antennas at base stations*

- *Diversity offers an improvement in the effective strength of the received signal by mitigating the multipath effects using:*

-Switched diversity: at a given moment, the system continually switches between antennas (connects each of the receiving channels to the best serving antenna)

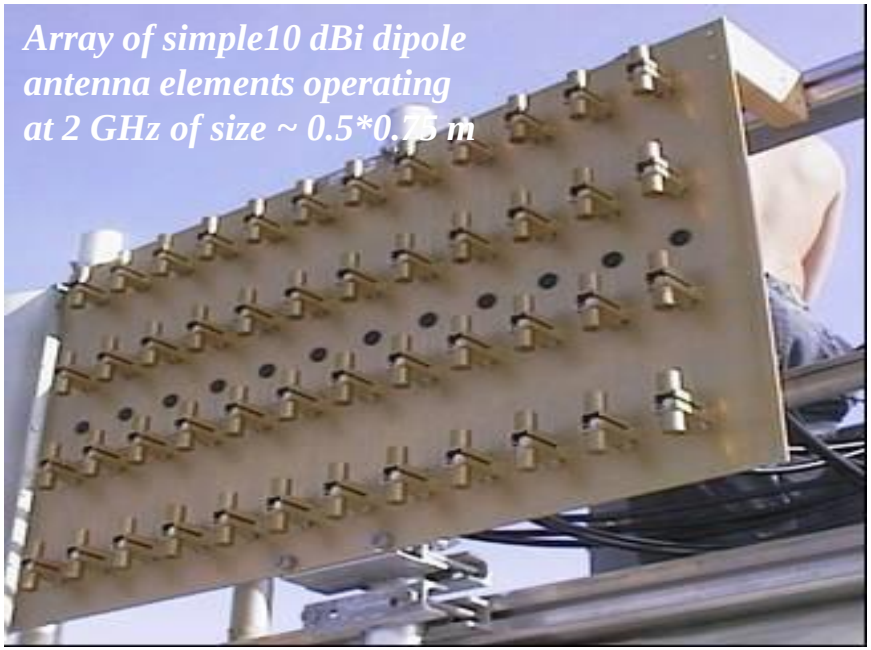
- Combining diversity : This approach corrects the phase error in two multipath signals and effectively combines the power of both signals to produce gain.

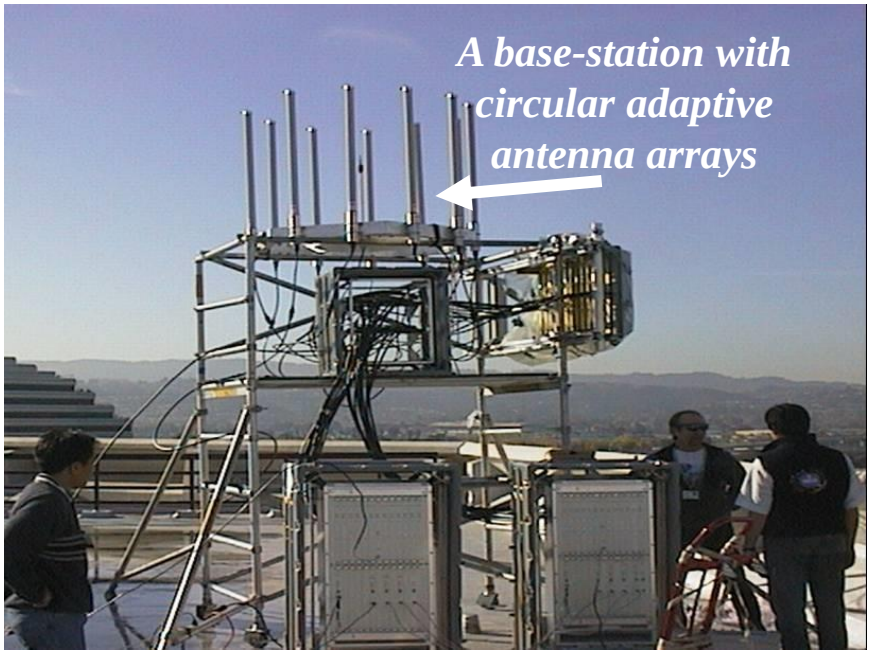
Other diversity systems, such as maximal ratio combining systems, combine the outputs of all the antennas to maximize the ratio of combined received signal energy to noise



•*Although this approach mitigates severe multipath fading, in high-interference environments, the simple strategy of locking onto the strongest signal or extracting maximum signal power from the antennas is clearly inappropriate and can result in clear reception of an interferer rather than the desired signal*

The need to transmit to numerous users more efficiently without compounding the interference problem led to the next step of the evolution antenna systems that intelligently integrate the simultaneous operation of diversity antenna elements (SMART ANTENNAS OR ADAPTIVE ANTENNAS)

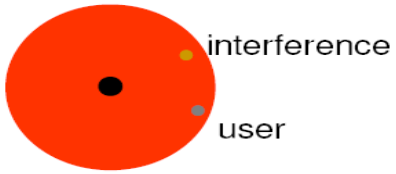




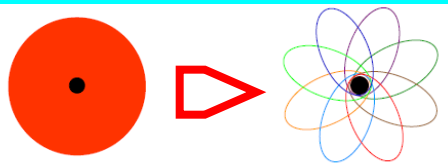
Hence, SA can integrate radio intelligence of the DSP with antenna array technology to:

Improve link quality for transmission and reception

Interference cancellation on the up and down links



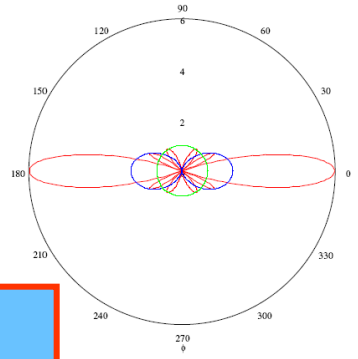
Provides N-fold diversity gain



SNR improvement due to antenna gain

Directionally send down link information

Mitigation of fading



Enhance communication system performance including

Capacity

Coverage range

Save energy

Quality of service, (QoS), Bit rate, Mobility rate

This can be accomplished by:

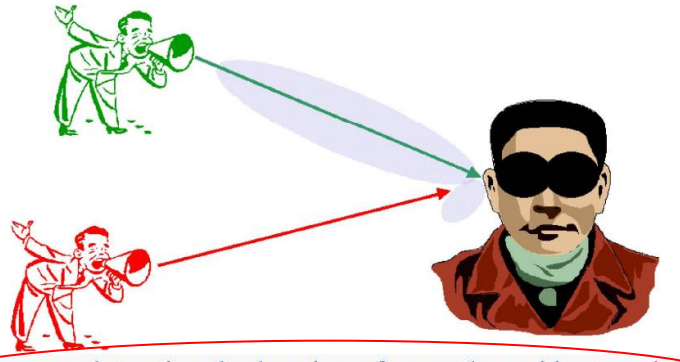
1-Beam steering: *direct the beam maxima to the signal of interest (SOI)*

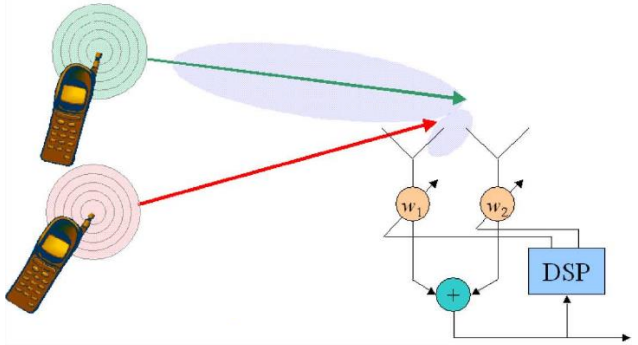
2-Beam nulling: *direct the beam minima to the signal not of interest (SNOI)*

3-Spatial diversity: *allowing different users to use the same spatial system resources (SDMA)*

here are many terms commonly used to describe SA (array antenna with processor to perform the beam steering) like
AA (if the adaptive algorithms involved) ,
intelligent antennas , digital beam forming, phased array with signal processor, spatial processing, SDMA,…

3-Analogy of auditory and electronic adaptation [18]





The listener can determine the location of a speaker without seeing him because of the following:

- He hears the speaker's voice through his acoustic sensors, his two ears.
- The speaker's voice arrives at each ear at a different time, time delay.
- His brain, a specialized signal processor, computes the location of the speaker from the time delays.
- His brain also adds the strength of the signals from each ear together, so as the perceived sound in the computed direction is louder than everything else.

If additional speakers join in the conversation

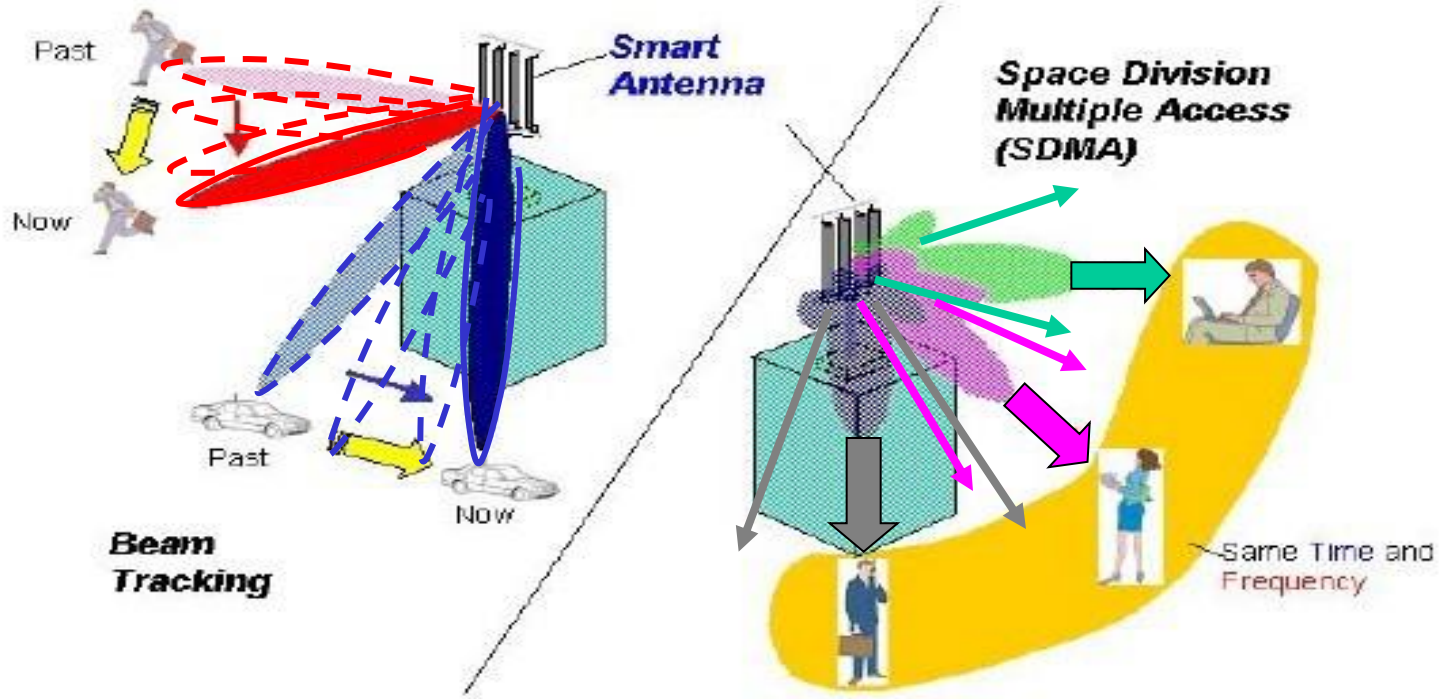
- The listener's brain can tune out unwanted interferers and concentrate on one conversation at a time.

An adaptive antenna system can determine the location of a user because:

- It receives the user's signal through its sensors/antenna elements.
- The signal arrives at each antenna element at a different time/time delay.
- Its DSP (Digital Signal Processor), a specialized signal processor, computes the Direction-Of-Arrival (DOA) of the user from the time delay.
- Its DSP also adds the strength of the signals from each antenna element together and forms a beam toward the direction as computed by DOA.

If additional users join in:

- The adaptive antenna system can tune out unwanted interferers by placing nulls toward the Signal-Not-Of-Interest (SNOI), and concentrate on the desired user by placing the main beam toward the Signal-Of-Interest (SOI).



Smart Antenna Technology

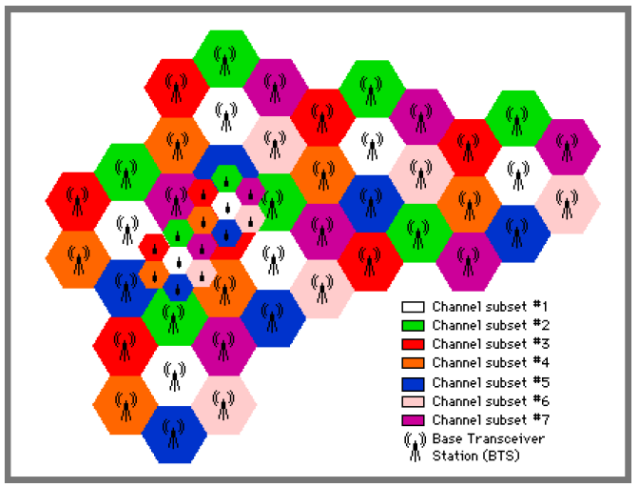
4-Definition of Smart or Adaptive Antennas (SA or AA)

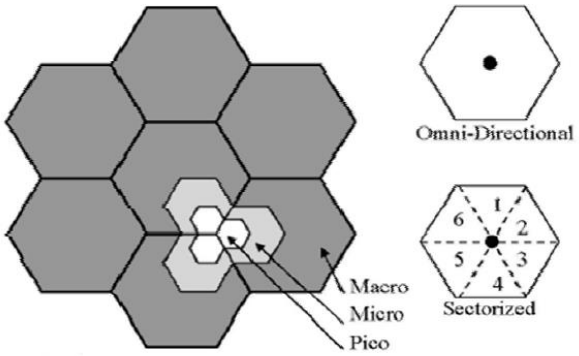
A system consisting of an antenna array and an adaptive processor that can perform filtering in both the space and frequency domain

An antenna that controls its own pattern, by means of feedback control, while the antenna operates. Some adaptive antennas also control their own frequency response

An adaptive or a smart antenna is an antenna array with a digital or adaptive signal processor in order to control its pattern direction and power intensity

Any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals

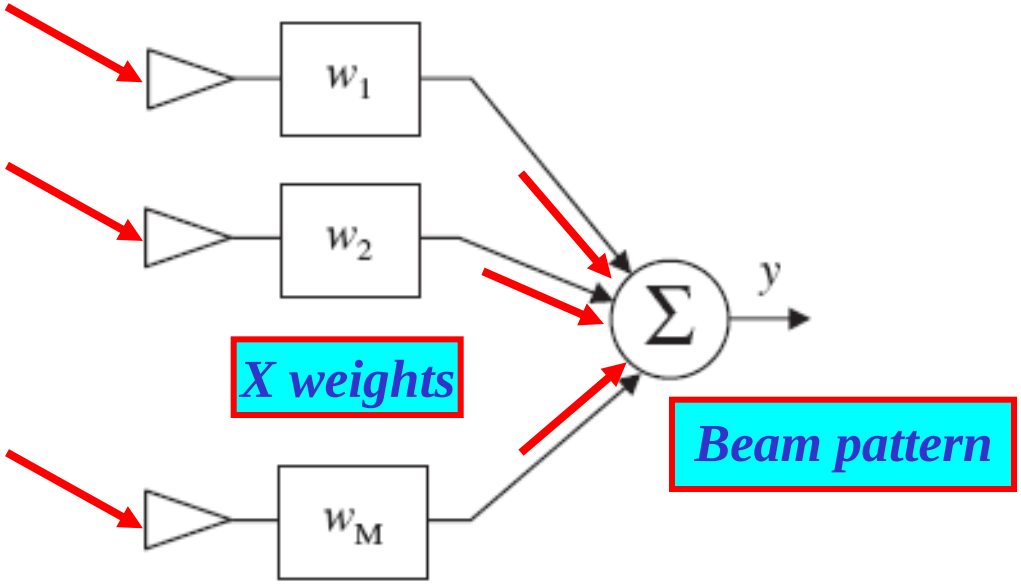




Typical block diagram of SA

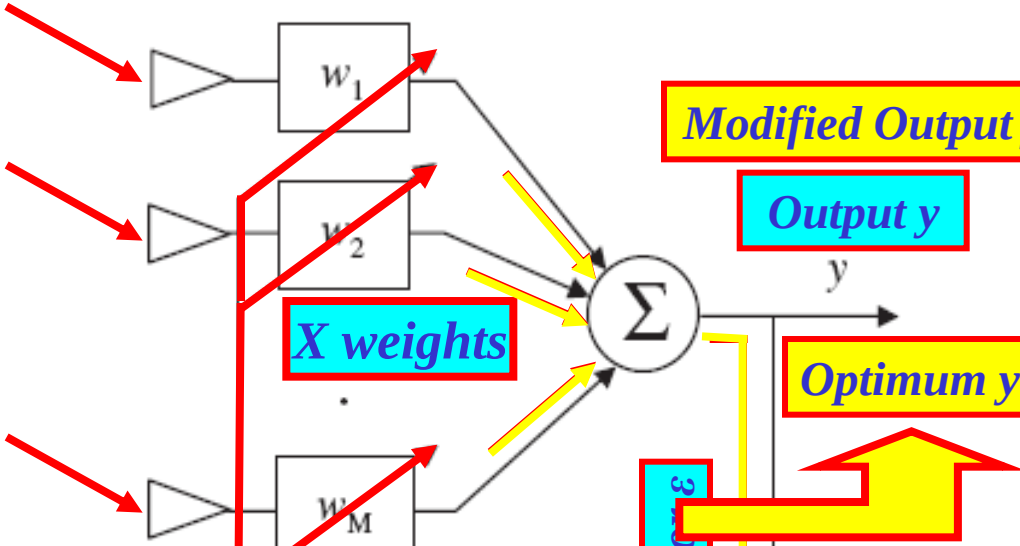
Is it an adaptive array?

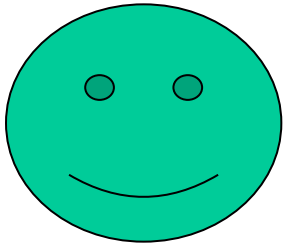
Is neither smart nor adaptive



It is a traditional antenna array

It is a fixed beam array where the main lobe can be steered by defining the fixed array weights w





It is an smart array

It needs a reference signal or DOA

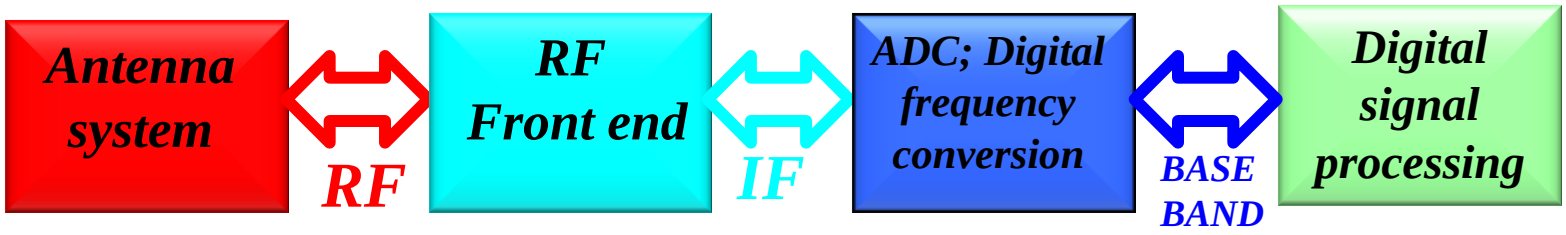
If the algorithms used are adaptive it is called adaptive array

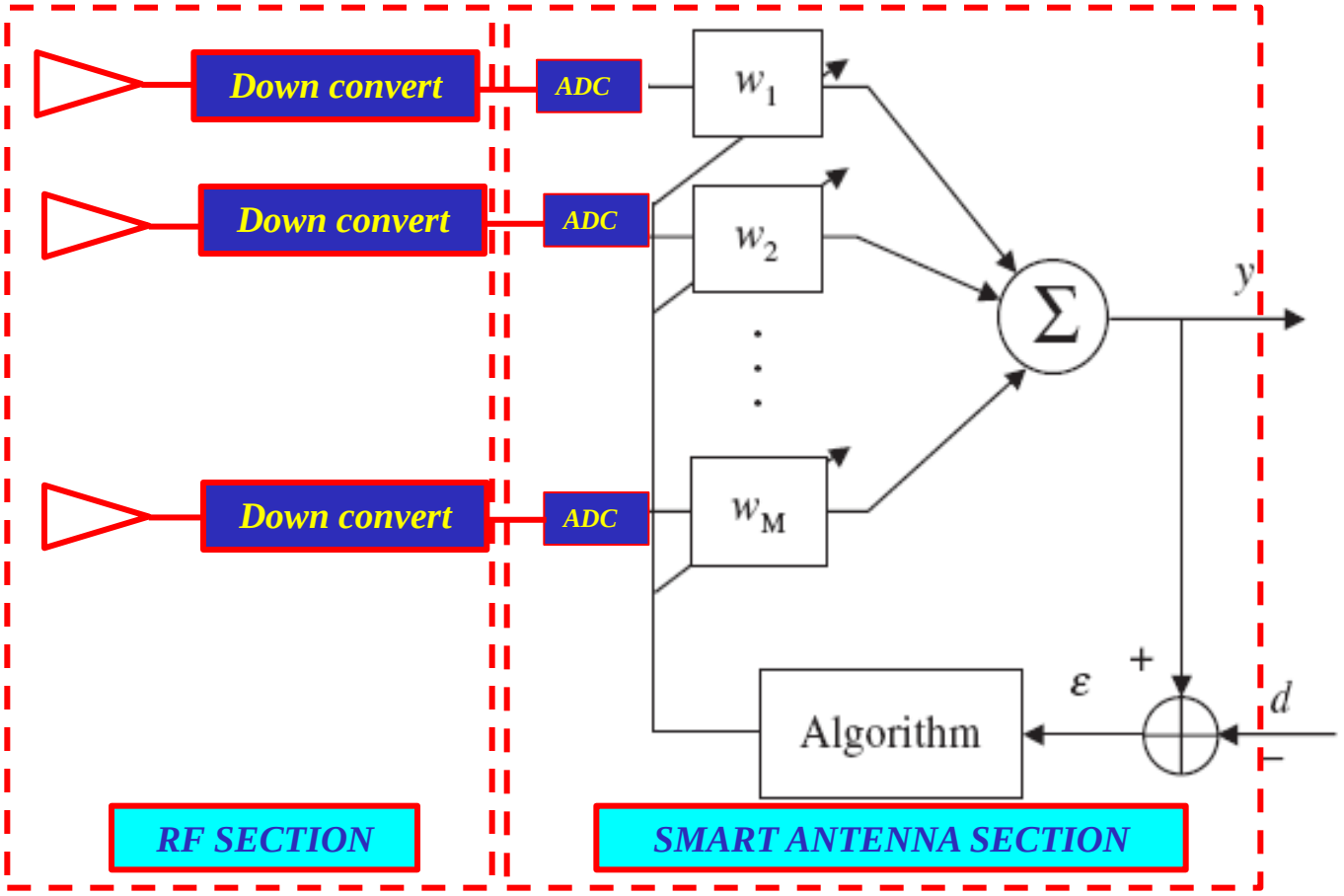
The complex weight computation based on different criteria is incorporated in the signal processor in the form of software algorithms

Components of SA (AA) System

- ***Antenna Array:*** *antenna elements are assumed to be identical with an nondirectional pattern in the azimuthally plane*
- ***Complex Weights:*** *they adjust the amplitude and phase of the signal which are computed by the DSP unit*
- ***Adaptive Signal Processor:*** *The weights are continuously adjusted by the adaptive signal processor (AA) in order to achieve the input function*

It should be pointed out that the signal processing is carried out in base band i.e.,:
-The signal is passed from each antenna element to the RF front end where LNPA, mixers and analogue filters are used for down conversion to IF
-The signal is converted to digital base band using ADC
-Combined using smart algorithm in a digital signal processor





The smart antennas or adaptive arrays can be abstracted to beam forming techniques

5-Evolution of practical SA as a part of practical system

First phase:

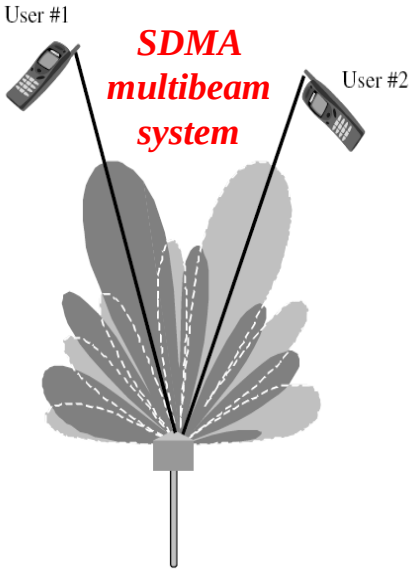
- Used on uplink only (user is transmitting and the base station is receiving)
- Increase the gain at the base station, both the sensitivity and range are increased, the concept is called high sensitivity receiver (HSR)
- Implemented in mobile communication systems

Second phase:

- Used on down (base station is transmitting and the user is receiving) in addition to HSR
- Increase the gain on both uplink and downlink, which implies a spatial filtering in both directions, the concept is called spatial filtering for interference reduction (SFIR)

Third phase:

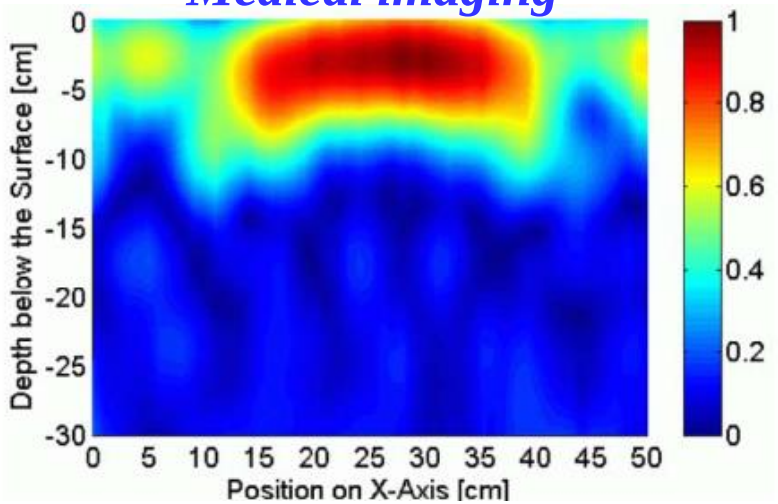
- Full space division multiple access (SDMA)
- More than one user can be allocated to the same physical communications channel simultaneously in the same cell separated by angle. Each beam former creates a maximum toward each of its desired user while nulling other users /interferers
- It is a separate multiple access method, but is usually combined with other multiple access methods (FDMA, TDMA, CDMA)
- SDMA allows more than 8 full-rate users (like GSM) to be served in the same cell on the same frequency at the same time by exploiting the spatial domain



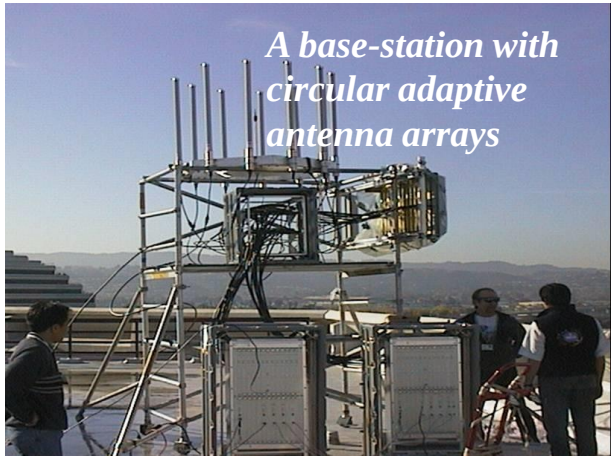
6-Applications of SA

Remote sensing

Medical imaging



Mobile communication



Sat. communication/navigation


Application on angle of arrival
(AOA)

7-Potential benefits of SA

- *Improved system capacities*
- *Higher permissible signal bandwidths*
- *Space division multiple access (SDMA)*
- *Higher signal-to-interference ratios*
- *Increased frequency reuse*
- *Sidelobe canceling or null steering*
- *Multipath mitigation*
- *Constant modulus restoration to phase modulated signals*
- *Blind adaptation*
- *Improved angle-of-arrival estimation and direction finding*
- *Instantaneous tracking of moving sources*
- *Reduced speckle in radar imaging*
- *Clutter suppression*
- *Increased degrees of freedom*
- *Improved array resolution*
- *MIMO compatibility in both communications and radar*

8- Drawbacks of SA

- *There transceivers are much more complex than traditional base station*

- *The antenna needs separate transceiver chains for each array antenna element and accurate real-time calibration for each of them*

- *The antenna beam forming is computationally intensive, i.e., smart antenna base stations must be equipped with very powerful digital signal processors*

This leads to increase the system costs in short term, but since the benefits outweigh the costs, it will be less expensive in long run

Summary

Since the main components of SA (AA) System are

- ***Antenna Array:*** *antenna elements are assumed to be identical with an omnidirectional pattern in the azimuthally plane*
- ***Complex Weights:*** *they adjust the amplitude and phase of the signal*
- ***Adaptive Signal Processor:*** *The weights are continuously adjusted by the adaptive signal processor in order to achieve the input function*

We should study the following

A revision on arrays and phased arrays

Narrowband and wideband beamforming (traditional beamforming)

Adaptive beamforming (adaptive signal processing)

References

1. Van Atta, L. "Electromagnetic Reflection," U.S. Patent 2908002, Oct. 6, 1959.
2. Howells, P. "Intermediate Frequency Sidelobe Canceller," U.S. Patent 3202990, Aug. 24, 1965.
3. Howells, P. "Explorations in Fixed and Adaptive Resolution at GE and SURC," IEEE Transactions on Antenna and Propagation, Special Issue on Adaptive Antennas,Vol. AP-24, No. 5, pp. 575–584, Sept. 1976.
4. Brock, D.K., O.A. Mukhanov, and J. Rosa, "Superconductor Digital RF Devel opmentfor Software Radio," IEEE Commun. Mag., pp. 174, Feb. 2001.
5. Liberti, J., and T. Rappaport, Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications, Prentice Hall New York, 1999.
6. Reed, J., Software Radio: A Modern Approach to Radio Engineering, Prentice Hall, New York, 2002.
7. Mitola, J., "Software Radios," IEEE Commun. Mag., May 1995.
8. Doufexi, A., S. Armour, A. Nix, P. Karlsson, and D. Bull, "Range and ThroughputEnhancement of Wireless Local Area Networks Using Smart Sectorised Antennas," IEEE Transactions on Wireless Communications, Vol. 3, No. 5, pp. 1437–1443, Sept. 2004.
9. Weisman, C., The Essential Guide to RF andWireless, 2d ed., Prentice Hall, New York 2002.
10. Stallings, W., Local and Metropolitan Area Networks, 6th ed., Prentice Hall, New York, 2000.
11. Skolnik, M., Introduction to Radar Systems, McGraw-Hill, 3d ed., New York, 2001.
12. Skolnik, M., "Attributes of the Ubiquitous Phased Array Radar," IEEE Phased Array Systems and Technology Symposium, Boston, MA, Oct. 14–17, 2003.
13. Lal, D., T. Joshi, and D. Agrawal, "Localized Transmission Scheduling for Spatial Multiplexing Using Smart Antennas in Wireless Adhoc Networks," 13th IEEE Workshop on Local and Metropolitan Area Networks, pp. 175–180, April 2004.
14. Wang Y., and H. Scheving, "Adaptive Arrays for High Rate Data Communications," 48th IEEE Vehicular Technology Conference, Vol. 2, pp. 1029–1033, May 1998.
15. Jeng, S., and H. Lin, "Smart Antenna System and Its Application in Low-Earth-Orbit Satellite Communication Systems," IEE Proceedings on Microwaves, Antennas, and Propagation, Vol. 146, No. 2, pp. 125–130, April 1999.
16. Durgin, G., Space-Time Wireless Channels, Prentice Hall, New York, 2003.
17. Ertan, S., H. Griffiths, M. Wicks, et al., "Bistatic Radar Denial by Spatial Waveform Diversity," IEE RADAR 2002, Edinburgh, pp. 17–21, Oct. 15–17, 2002.
18-C.A. Balanis "Antenna theory analysis and design", John Wiley and Sons