MIMO Systems:[1]

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MIMO Systems

- Introduction
- Space diversity and system based on space diversity
- Smart antenna systems and MIMO
- MIMO based system architecture
- MIMO exploits multipath
- Space time processing
- Antenna considerations for MIMO
- MIMO channel modeling
- MIMO channel measurements
- MIMO channel capacity, , , , ,
- Cyclic Delay Diversity
- Space time coding
- advantages and applications of MIMO
- MIMO application in 3G
- MIMO OFDM

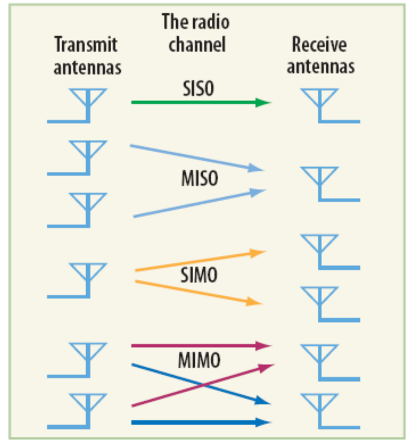
Introduction

- There are three basic performance parameter that completely describe the quality and usefulness of any wireless link: **speed, range and reliability.**
- MIMO use multiple inputs and multiple outputs from a single channel are defined by Spatial Diversity and Spatial Multiplexing.
- Why MIMO? There is always a need for increase in performance in wireless systems Significant increase in spectral efficiency and data rates, High Quality of Service (QoS) Wide coverage, etc.
- The transmission in wireless communication system is typically organized in packets ,with training sequence at the beginning of the packet,to allow for channel estimation and coherent detection of the receiver.
- There are different modes of operation possible and the preference depends on the SNR,channel conditions,and constraints imposed on the system complexity.
- examples of open-loop MIMO techniques include antenna subset selection, maximum ratio combining (MRC),spatial multiplexing(SMX),cyclic delay diversity(CDD),and space time block coding(STBC).

Space diversity and system based on the space diversity

Space diversity and system based on the space diversity

- In space diversity the signal is transmitted over several **different propagation paths**.
- In wireless communication, it can be achieved by **antenna diversity** using **multiple** transmitter antennas and/ or receiving antennas.
- After receiving the signal at the receiver **combining technique** is used for further processing.
- If the transmitting or receiving antennas are far distance, for example at different cellular base station sites or WLAN access points, the diversity is called **macro diversity**. If the transmitting or receiving antennas are at a distance in the order of one wavelength, this is called **micro diversity.**



- Presently **four** different types of systems can be categorized as for as diversity is concerned.
  1. **Single input-single output (SISO)**: No diversity
  2. **Single input-multiple output(SIMO)**: Receive diversity
  3. **Multiple input-single output (MISO)**: Transmit diversity
  4. **Multiple input-multiple output(MIMO)**: Transmit-receive diversity

- The SISO system is very simple and deals with communication between a transmitter and receiver. in SISO error probability is critically damaged by fading.
- In SIMO channel, the concept of Maximum Ratio combining (MRC), is used to exploit the receive diversity.
- The error probability is to be much smaller than the the SISO channel.
- To perform MRC, the receiver has to know the channel state information (CSI).
- The CSI is usually done by sending some known signal through the channel.
- Cellular communication environment is considered as the SIMO, where mobile stations have single transmitting antenna and base station can have have K multiple adaptive antennas.
- Figure shows the SIMO environment where L signals are arrive at each base station from different terminals with different amplitudes α_i and phases ϕ_i at different delays τ_i from different direction θ_i.
- The channel impulse response (CIR) for each antenna is represented as:

$$h(t) = \sum_{l=1}^{L} [\alpha_l(t) e^{j\phi(t)}] \delta[t - \tau_l(t)] a[\theta_l($$

- The channel impulse response is vector of K elements for K antennas of the receiver.
- The amplitudes are assumed to be Rayleigh distributed.

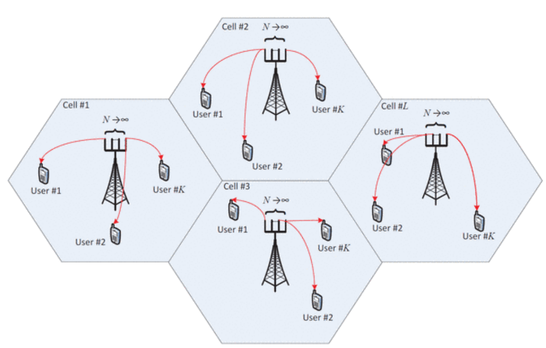
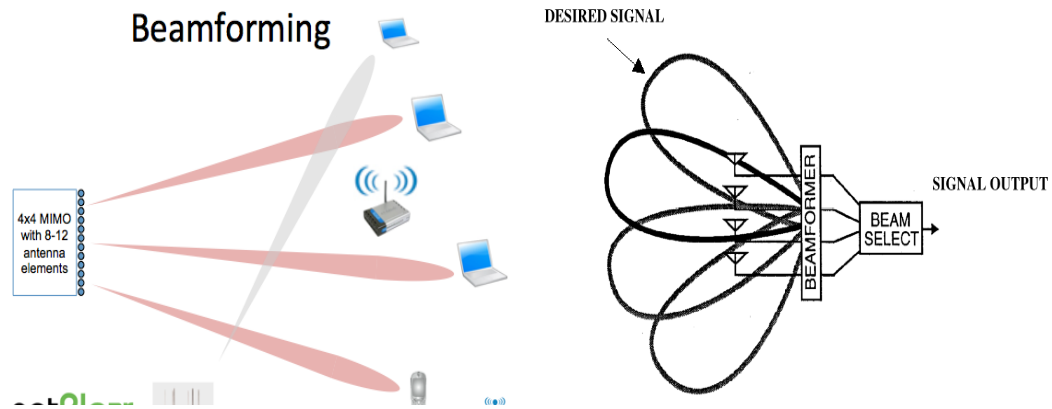


Figure 1: SIMO example.

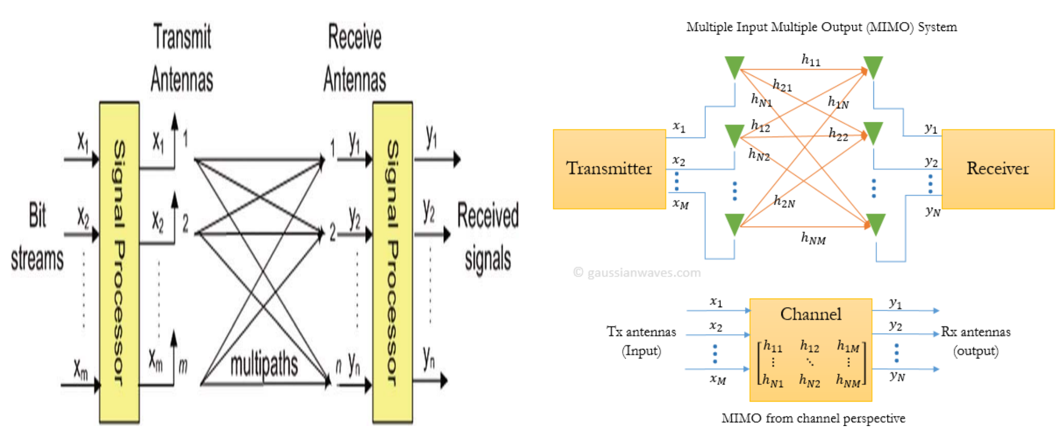
- When there are I antenna elements in a mobile and one base station antenna element it makes an MISO channel.
- The channel response is an $I \times 1$ matrix
- In MISO beam forming technique i.e., directional reception is used.
- By using beam forming the average SNR is increased through focussing the energy into desired directions.
- Transmit beam forming achieves a diversity of order K and an antenna gain of K
- For transmit beam forming the transmitter must have the CSI by transmitting training sequences.



(a) Beam forming (b) Beam forming

Figure 2: Beam forming

- In MIMO both transmit diversity and receive diversity is achieved.
- MIMO transmits the multiple signals in parallel across the communication channel and has the ability to multiply the capacity of the system.
- The channel capacity i.e Spectral efficiency is the number of units of information per unit of time per unito of radio bandwidth, usually denoted in bits per second per hertz $b/s/Hz$.
- In MIMO, channel duplex methods time division duplex (TDD) and frequency division duplex (FDD) is used.
- In FDD feedback channel from receiver to the transmitter provides CSI to the transmitter.
- This information will be used to adjust the data transmission.



(a) MIMO (b) MIMO

Figure 3: MIMO

Channel capacities of SIMO, MISO, MIMO systems

- SISO:capacity is given by Shannons classical formula:

$$C = B\log_2(1 + SNR) \tag{1}$$

  Where B is the BW .
- SIMO with M antennas at receiver end. suppose the signals received on these antennas have the same amplitude and average.hence SNR is given by the

$$SNR = \frac{M^2(Signalpower)}{M.Noise} = M.SNR \tag{2}$$

  capacity is given by

$$C = B\log_2(1 + M.SNR) \tag{3}$$

- MISO with N transmitting antennas,the total transmitted power is divided into N branches.there is only one receive antenna so noise power is same as SISO. hence overall increase in SNR given by

$$SNR = \frac{N^2(Signalpower/N)}{Noise} = N.SNR \tag{4}$$

the capacity is given by

$$C = B\log_2(1 + N.SNR) \tag{5}$$

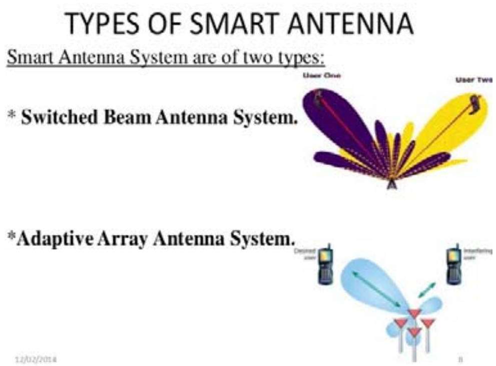
- The MIMO system can be viewed ,in effect as a combination of MISO and SIMO system.hence channel capacity equals to

$$C = B\log_2(1 + MN.SNR) \tag{6}$$

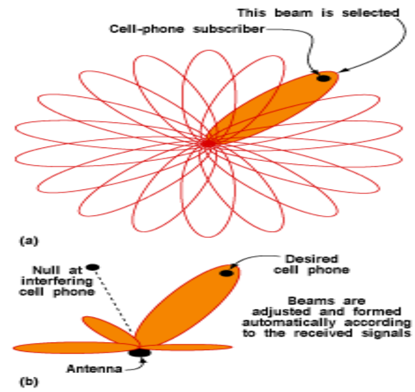
Smart antenna system and MIMO

Smart antenna system

- Smart antennas are designed to help wireless operators cope with variable traffic level and the network inefficiencies they cause.
- These system also allow carriers to change gain setting to expand or contract coverage in highly localized area, all without climbing a tower are mounting another custom antenna.
- Usually smart antennas are colocated with the base station, it combines an antenna's array with a digital signal processing capability to transmit and receive in an adaptive, spatially sensitive manner.
- Smart antenna system can automatically change the directionality of it's radiation patterns in response to its signal environment.
- They can increase the performance of a wireless system dramatically.
- The system locate users, track them, and provide optimal RF signals to the user as they move through a base stations coverage.
- The terms associated with smart antenna are phased array, SDMA, spatial processing , digital beam forming adaptive antenna systems.
- The smart antenna system fall into two main categories : switched beam system and adaptive array system.
- Each approach directs a main lobe towards the individual users and attempts to reject interference or noise from outside of that main lobe.

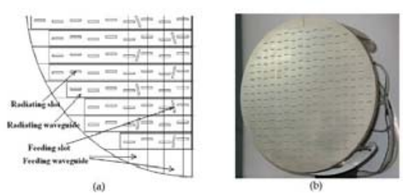


(a) Smart-antenna

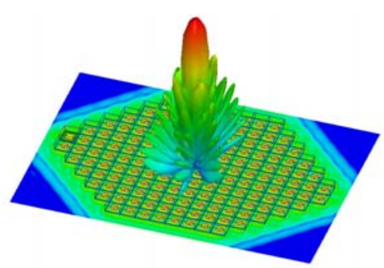


(b) Smart-antenna

Figure 4: Smart-antenna

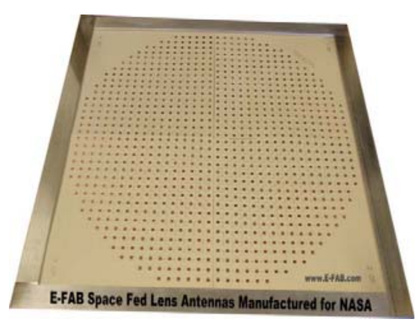


(a) Array-antenna



(b) Array-antenna

(c) Array-antenna



(d) Array-antenna

Figure 5: Array-antenna

How MIMO differs from smart antenna

- The smart antennas enhance conventional, one dimensional radio system.
- The most common smart antenna systems use **beam forming or transmit diversity**(Figure 6) to concentrate the signal energy on the main path and receive the **combination**(Figure 7) to capture the strongest signal at any given movement.

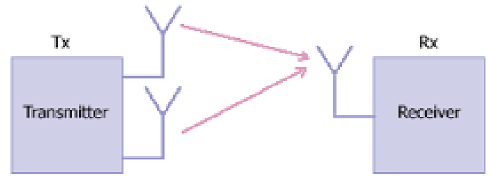


Figure 6: Beam forming using two transmit antenna.

- The beam **forming and receive combining** are only **multipath mitigation techniques** and **do not multiply data throughput** over the wireless channel.
- Both combined together as shown in Figure 8 demonstrate an ability to improve performance incrementally in point to point application.

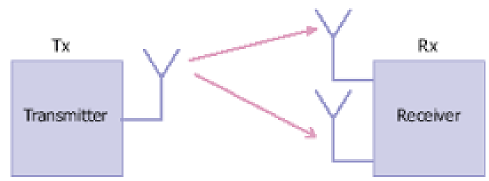


Figure 7: Diversity using two receive antennas.

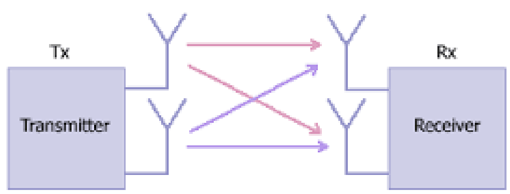
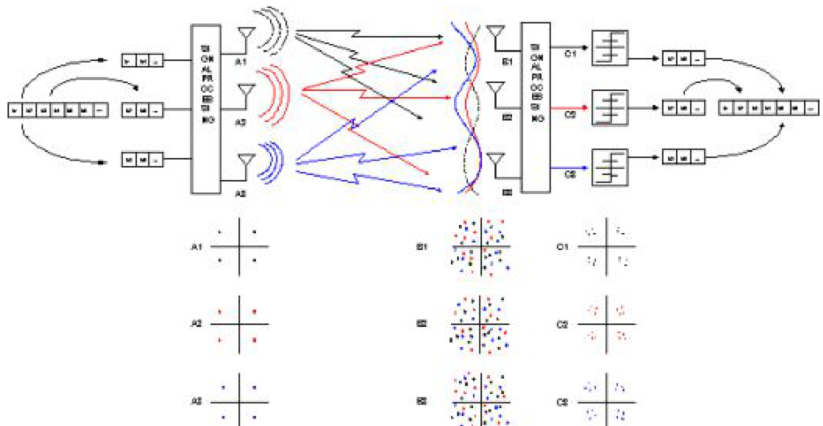


Figure 8: MIMO uses multiple Tx and RX antennas.

- The transmitted information by both the antenna is different.
- Receiver combining and beam forming increases the spectral efficiency by one or two b/s/Hz at a time, MIMO multiplies the b/s/Hz.
- Powerful effect of smart antenna is that in the presence of random fading caused by multipath propagation the probability of error decreases exponentially with the number of decorrelated antenna elements being used.
- In particular, MIMO system can provide a joint transmit receive diversity gain, as well as array gain upon coherent combining of the antenna elements.
- Another advantage of MIMO is ability to jointly code and decode multiple streams since these are intended for the same use.
- The serial data is converted to parallel and this parallel data is transmitted simultaneously, this will increase the spectrum efficiency.

- Consider a M= 3 number of antennas in the transmitting side and have K (b1, b2, b3, b4, b5, b6) = 6 bits for sending.
- Divide the bits into M=3 sub streams of data (b1, b3), (b2, b4), (b3, b6) then modulate each sub stream of data with three carrier frequency and transmit them via three separate antennas.
- If all the sub-streams had to be transmitted by one carrier then the bandwidth consumptions would be three time greater-this is one of the great advantage of spatial multiplexing
- At the receiver each sub-stream will have three spatial signatures-that means total 9 spatial signature will be at the receiving antenna-due to the multipath environment each sub stream will have its own spatial signature.
- Based on this spatial signature sub-streams of data will be demultiplexed and decoded in order to get back the original data stream-this is how spatial multiplexing works



Mimo Based System Architecture

- The MIMO system can be represented as an arbitrary wireless communication system.
- A core idea in an MIMO system is space time signal processing in which time is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas.
- Serial data stream converted into parallel streams and can be processed separately.
- The blocks will be as source coding, channel coding modulation and RF up conversion blocks on the transmitter side and opposite at the receiver side but may be individual for individual antenna element or some two dimensional signal processing methods may be used.
- The digital signal processing is used to separate the multiple streams in MIMO at the receiving end.
- The problem cannot be solved because the system of linear equation is dependent, and the antennas are strongly correlated to one another, which are in influenced by spacing, polarization, radiation pattern.

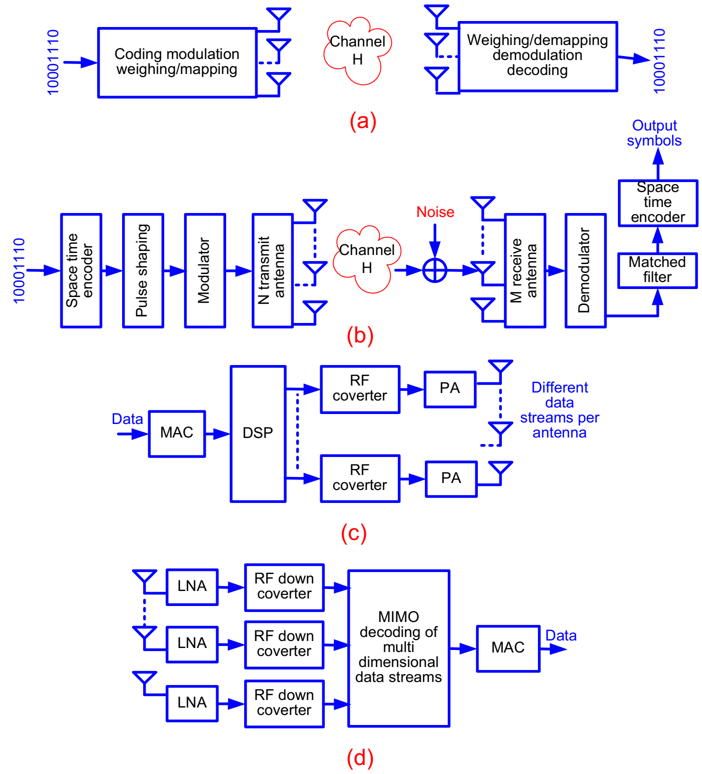


Figure 10: MIMO uses multiple Tx and RX antennas.

MIMO exploits multipath

- In multi path propagation there is usually a **primary path** from a transmitter to receiver and some of the transmitted signals take other path to the receiver, bouncing of objects, the ground, or layers of atmosphere.
- The signal traversing **NLOS** arrive at the receiver later and are attenuated as shown in figure 11.
- A common strategy for dealing with weaker multipath signal is to simply ignore them, in which case the energy they contain is wasted. the strongest multipath signals may be too strong to ignore and also can degrade the performance of wireless equipment.

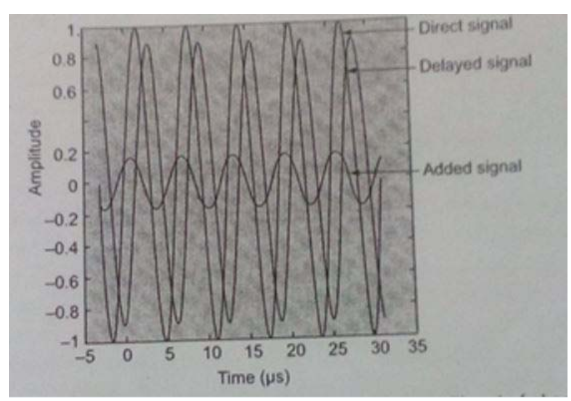


Figure 11: Multipath effect.

- Radio signals can be depicted on a graph in the form of sine wave with vertical axis indicating amplitude and horizontal axis indicating time.
- From the figure it is clear that multipath signal arrives slightly later than the primary signal, its peaks and troughs are not quite aligned with those of primary signal and the combined signal seen by the receiver is some what attenuated and blurred.

- As shown in Figure 12 if delay is sufficient to cause the multipath signal's peaks to line up with the primary signal's troughs, multipath signal will partially or totally cancel out the main signal
- The strongest signal in each movement in time is received or adds different delays to received signals to force the peaks and troughs back into alignment.

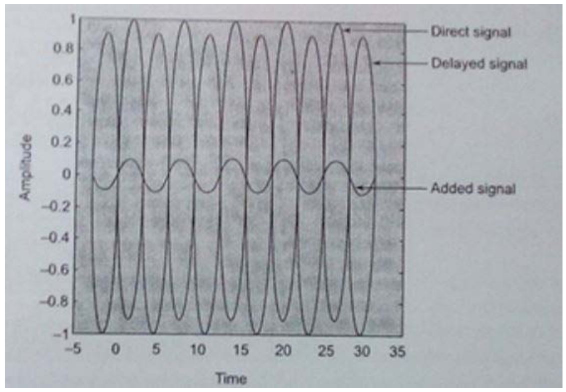


Figure 12: Multipath effect.

- The same concept is used in MIMO and MIMO takes advantage of multipath propagation.
- In MIMO multipath signals carry more information using parallel paths.
- This is done by sending and receiving **more than one data signal in the same radio channel at the same time using different antennas**.
- The MIMO system has the ability to reject fading and thereby improved reliability.

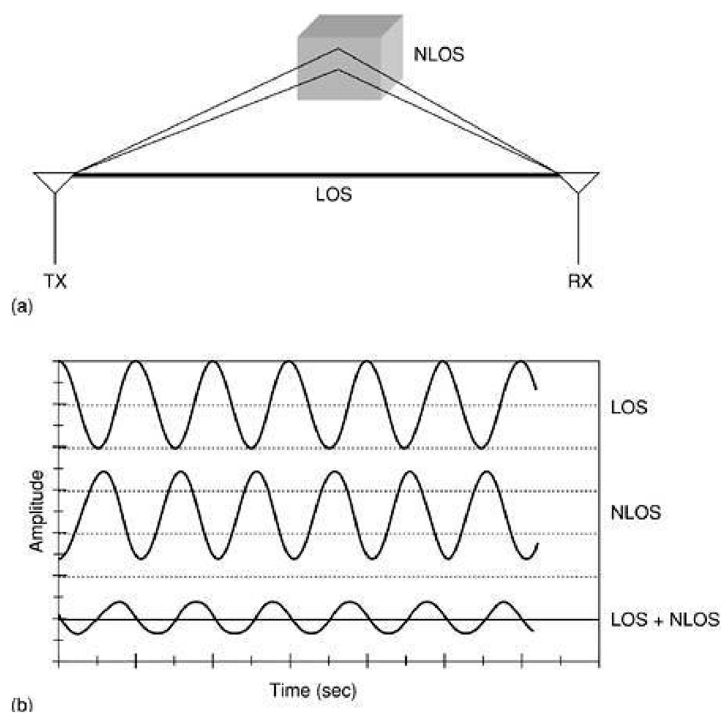


Figure 13: Multipath effect.

Multipath diversity reception in multi antenna receiver

- The signal strength received is dependent upon the carrier frequency as the wireless channel is the dielectric media in which the phase velocity of different waves will be different and reach the receiver at a different instant of time.
- A signal transmitted at a particular carrier frequency and at a particular instant of time may be received in a multipath null.
- The diversity reduces the probability of occurrence of communication failures caused by fades by combining several copies of the same message received over different channels.
- One M-branch receiver is shown in Figure 14, in which phase shifters and attenuators are used to align the signals in terms of phase and amplitude and finally maximum ratio combining is used to combine the signal.
- For 1*M situations, the maximum ratio combining takes the M received signals and perform coherent superposition (adder), corresponding to optimal maximum likelyhood detection.
- Before coherent superposition stage, each signal branch is multiplied by a weight factor, which is proportional to the signal amplitude, that is, a branches with strong signal or further amplified, while the weak signals are attenuated.
- The idea to boost the strong signal components, as performed in MRC diversity, is exactly same as type of filtering and signal weighting used in matched filter receiver.

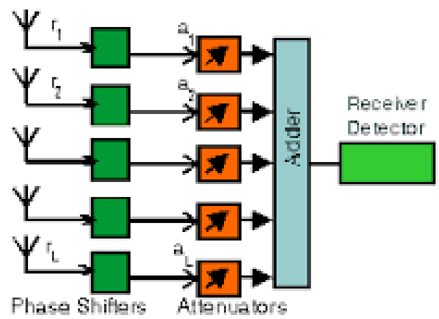


Figure 14: M-branch antenna diversity receiver

Space-time processing

- The space-time processing uses the **spatial dimention along with the traditional temporal modulation** and coding at the transmitter along with advanced decoding at the receiver making parallel transmission possible and thus launching the concept of STP.
- A conceptual diagram is given in figure. the STP can improve spectral efficiency as well as coverage area.
- It makes better use of spectrum and allows support of multiple users and reduces power requirements.

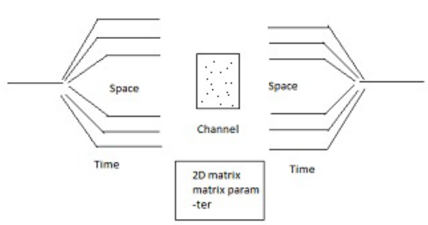


Figure 15: Scatterers concentrated around the mobile station.

Spatial multiplexing

- In spatial multiplexing diffract information is transmitted simultaneously over **N transmit antennas** increasing the **data rate** at short distance and providing **high spectral efficiency**
- The spatial multiplexing is sometime also referred as **direct transmission or MIMO.**
- The spatial multiplexing is shown in Figure 16 which improves the **average capacity behavior** by sending as many independent signals at specific error rate .

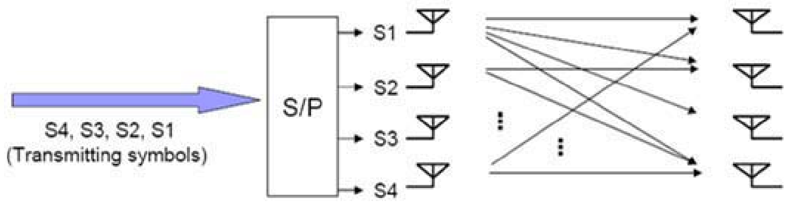


Figure 16: Example of spatial multiplexing

- Layered space-time architecture exploit the spatial multiplexing gain by sending independently encoded data streams in diagonal layers using **Diagonal Bell Laboratories Layered Space-Time Architecture** (D-BLAST) as originally proposed or in horizontal layers, which is so called vertical layered space-time(V-BLAST) (Vertical Bell Laboratories Layered Space-Time Architecture).

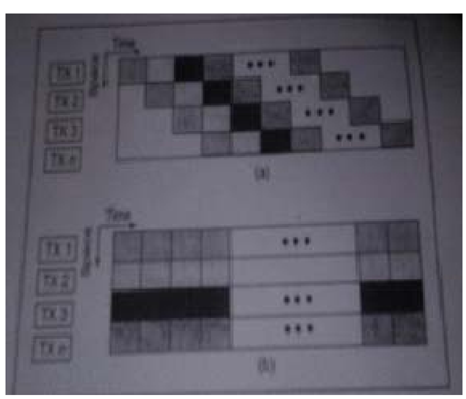


Figure 17: Example of spatial multiplexing

Spatial multiplexing vs spatial diversity

- **Spatial diversity**is used to increase the **diversity order** of MIMO link to mitigate **fading** by coding a signal across space and time so that a receiver can receive the replicas of the signal and combine those receive signals constructively to achieve a **diversity gain**.
- Pure multiplexing allows for full independent use of antennas, but it gives limited diversity benefit and is rarely the best transmission scheme for a given BER target.
- The possibility of linear capacity growth with number of antenna is good,especially knowing that increasing power(SNR).

Antenna consideration for MIMO

- Multiple antenna system can improve the **capacity** and **reliability** of radio communication.
- The multiple RF chains associated with multiple antennas are costly in terms of size, power, and hardware.
- The antenna selection is a **low cost, low complexity** alternative to capture many of the advantages of MIMO system.
- It can reduce hardware complexity and cost, achieve full diversity and, in the case of transmit antenna selection, achieve capacity.
- The MIMO signalling improves wireless communication in ways such as **diversity and spatial multiplexing**.
- The **selection diversity** approach selects the best antenna with the **highest received signal power**.
- There are two main approaches to antenna selection :
  1. **Norm-based selection**
  2. **Successive selection**
- The former approach is more suitable when the SNR is low, where as the latter suits the high SNR regime.
- The antenna selection has a certain inherent limitations in which one of the most important limitation arises whenever the system bandwidth is larger than coherence bandwidth of the channel.

Antenna separation in micro-diversity system

- In **micro-diversity**, the signal from antennas mounted at separate locations are combined
- Typically, these antennas are located on the vehicle are at the same base station tower and their **spacing is a few wavelengths**.
- The received signal amplitude **correlation** is depending on the antenna separation**distance** d **relative to the wavelength**.
- The received multipath signal is **uncorrelated** if the antennas at the mobile are spaced by **more-than, half wavelength**.

MIMO Channel Modelling

- Wireless channel signal is a sum of two components
  1. Line-of-sight (LOS) component
  2. Non-line-of-sight (NLOS) component

LOS components

- The ratio between the power of the LOS component and the mean power of the NLOS component is Rician factor.
- For MIMO system, higher the Rician factor K, the more dominant NLOS and NLOS is time invariant.
- The Rician factor is a function of season, antenna heights, and distance.
- In a fixed wireless network (macrocell), MIMO improves the quality of service in areas that far away from the base station or are physically limited to using low antennas.
- In a metropolitan city (microcell), antenna height is low, and in an indoor environment simulation and measurement have shown that multipath scattering is rich enough that the LOS components rarely dominates.
- This plays in favor of in-building MIMO deployment(eg:WLAN)

Space Time Coding (STC)

- A STC is a method to improve the reliability of data transmission in wireless communication system using multiple transmit antennas.
- The STCs rely on transmitting multiple, redundant copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between the transmission and the reception in a good enough to state to allow reliable decoding.
- The space-time codes are of two types: space-time trellis code and space-time block codes.
  1. **Space-time trellis code(STTC)**
  2. **Space-time block codes(STBC)**

Space-time trellis code(STTC)

- STTC distribute trellis code over multiple antenna and multiple time slot providing both coding and diversity gains.
- This scheme transmits multiple, redundant copies of a trellis code distributed over time and a number of antennas ('space').
- These multiple 'diverse' copies of the data are used by the receiver to attempt to reconstruct the actual transmitted data.
- For an STC be used there must necessarily be multiple transmit antennas, but only a single receive antennas is required.

Space-time block codes(STBC)

- STBC act on a block of data at a time and provides only diversity gain, but they are much complex in implementation than STTCs.
- The STTCs rely on Viterbi decoder at the receiver at the receiver whereas STBCs requires only linear processing.
- The space time code subdivided into coherent and non coherent based on receivers knowledge.
- **In coherent STC** ,the receiver knows the channel impairments through training or some other form of estimation.these codes have been studied more widely bcz ther are less complex than their non-coherent counterparts.
- **In non coherent STC**, the receiver does not knows the channel impairments but knows the statistics of the channel.
- **In differential STC**, neither the channel nor statistics of the channel are available to the receiver.
- These STCs are usually based on space-time block code and transmit one block code from a set in response to a change in the input signal.
- These differences among the block in the set are designed to allow the receiver to extract the data with good reliability.

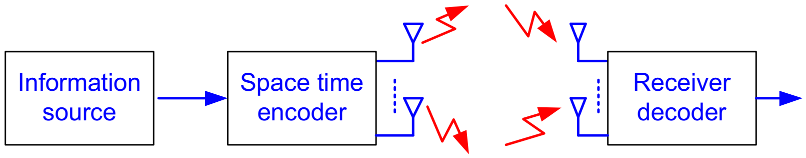


Figure 18: Space time coding in MIMO.

- From the fig, for each input symbol from the information source, the space-time encoder chooses the constellation point and it simultaneously transmit it from different antennas at different time slots giving coding and diversity gain.
- For an STTC, both coding and diversity gains can be obtained,but for STBC,only diversity and some coding gain depending on the code rate can be obtained.
- In the model,if there are N transmitting and M receiving antennas,then the channel is made up of N×M sub-channel and in each channel,fading effect are there.
- At any time slot,N signals are transmitted simultaneously,one from each transmit antenna.
- The transmitted signals in the sub channels undergo independent fading and the fading coefficient are assumed to be fixed during a fixed time slot and are independent from one slot to another.

- The transmitted code vector is $\vec{s} = [s_1, s_2, ..., s_{Nt}]$ and any channel can be modelled as multiplications by complex number h,which is called the fade coefficient.
- The receiver antenna will pick up noise,which is modelled by a complex number η
- the received code vector can be expressed as

$$r = hs + \eta$$

- For N transmitting antenna and a single receiving antenna, then the received signal is

$$r = h_1 s_1 h_2 s_2 + ... + h_N s_N + \eta$$

- For M receiving antenna,then we have fade coefficients $h_{ij}(0 < i <= Mand0 < j <= N)$
- For each corresponding path between transmitter j and receiver i,we have noise at each receiver.then we have eqn of ith receiver signal as $r_i = h_{i1}s_1 + h_{i2}s_2 + ... + h_{iN}s_N + \eta_i$.
- If we consider the channel as a whole by expressing M equation as a single matrix equation, then we have

$$\begin{pmatrix} r_1 \\ r_2 \\ . \\ . \\ r_M \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & . & . & h_{1N} \\ h_{21} & h_{22} & . & . & h_{2N} \\ . & . & . & & . \\ . & . & & . & . \\ h_{M1} & h_{M2} & . & . & h_{MN} \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \\ . \\ . \\ s_N \end{pmatrix} + \begin{pmatrix} \eta_1 \\ \eta_2 \\ . \\ . \\ \eta_M \end{pmatrix}$$

- In vector form equation can be written as $\vec{r} = H\vec{s} + \vec{\eta}$

Space-time block coding(STBC)

- with CDD,space-time block codes can be viewed as repetitions codes over space and time,simultaneously transmitting the same data over different antennas.
- Similar to MRC, a fading channel can be more AWGN-like using these techniques,providing increased robustness and range extension.
- The space-time block code achieve significant error rate improvement over single-antenna systems.
- Their original schemes was based on trellis code but the simpler block codes were utilized by S.
- The space-time block code in itself is not a code but is a techniques to transmit multiple copies of a data streams across a number of antennas ant to exploit the various received version of the data to improve the reliability of data transfer.
- The STBC can be represented by a matrix showing the symbol transmitted through a given antenna at a given time slot. these matrix can be shown below

- STBC matrix showing the symbols to be transmitted by given antenna in a given time slot

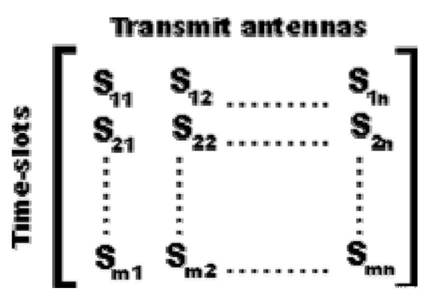
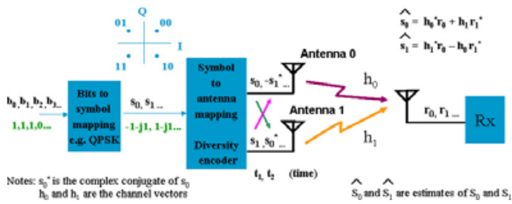
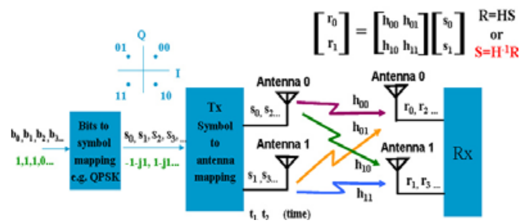


Figure 19: Space time coding in MIMO.

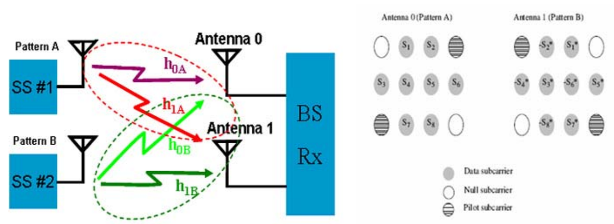
- Here s_{ij} is the modulated symbol to be transmitted in time slot i from antenna j. There are to be T m times slot and N transmit antennas as well as M receive antenna.
- This block is usually considered to b of length T.The code rate of an STBC measures how many symbols per time slot in transmit on average over the course of one block.
- If a block encodes K symbol, the code rate is
  r=k/T



(a) STBC coding



(b) STBC coding



(c) STBC coding

Figure 20: STBC coding

Space-time block coding(Alamouti's code)

- The simplest form of space-time block codes was invented by alamouti in 1998.He proposed this techniques for two transmitter antenna and one receiver antenna.
- The transmission matrix is square and satisfies the condition for complex orthogonality in both space and dimensions.this is a very special STBC.
- This code is designed for two transmit antenna system and the code matrix is given as
  $C_2 = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix}$
- where $*$ is denotes complex conjugate
- Here,two time slots are required to transmit two symbol.thus,k=2 and T=2 hence,the code rate for almouti's code is 1.

Encoder

- An encoder consists of symbol calculation and then transmitting the symbols over the transmitter antenna over different time slots.
- Consider digital modulation scheme with 2^b constellation elements,where b is the number of bits per symbol,e.g., QPPSK,BPSK,and 16-QAM.
- AT time t1,say,2b bit arrive at the encoder and they pick up constellation symbol s1 and s2.
- This is shown in the block diagram in fig

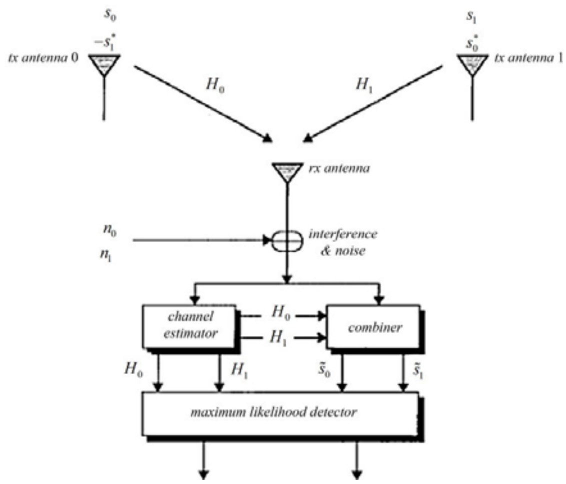


Figure 21: Space time coding in MIMO.

Decoder

- The STBC linearly process the received symbol and uses maximum likelihood decoding.
- The received signal is the linear superposition of the transmitted elements corrupted by AWGN and channel fading.
- The receiver model for alamouti's code can be shown in fig.

- The two transmitter Tx 1 and Tx 2 transmit the signals simultaneously. Also,its assumed that the fade coefficient of the channel are constant throughout one time slot.
- The received signal r1 and r2 can be written as
$$r_1 = h_1 s_1 + h_2 s_2 + n_1$$
$$r_2 = -h_1 \bar{s}_2 + h_2 \bar{s}_1 + n_1$$
- In the combiner aided by the channel estimator,which provides perfect estimation of the diversity channel in the eg,simple signal processing in order to separate the signal s1 and s2.Specifically,the maximum likelihood detector minimizes the
$$|r_1 - h_1 s_1 - h_2 s_2|^2 + \left| r_1 + h_1 \bar{s}_2 - h_2 \bar{s}_1 \right|^2$$
for all received code words over all possible values of s1 and s2.
- Expanding the above metric and depending the term independent of code words,we get
$$-\left[r_1 \bar{h}_1 \bar{s}_1 + \bar{r}_1 h_1 s_1 + r_1 \bar{h}_2 \bar{s}_2 + \bar{r}_1 h_2 s_2 - r_2 \bar{h}_1 \bar{s}_2 + \bar{r}_2 h_1 \bar{s}_2 + r_2 \bar{h}_2 s_1 + \bar{r}_2 h_2 \bar{s}_1 \right] + \left(|s_1|^2 + |s_2|^2\right)\left(|h_1|^2 + |h_2|^2\right)$$

- Which can be further decomposed in to two parts
$$-\left[r_1 \bar{h}_1 \bar{s}_1 + \bar{r}_1 h_1 s_1 + r_2 \bar{h}_2 s_1 + \bar{r}_2 h_2 \bar{s}_1 \right] + |s_1|^2 \left(|h_1|^2 + |h_2|^2\right)$$
which is a function of s1 only,and the other part
$$-\left[r_1 \bar{h}_2 \bar{s}_2 + \bar{r}_1 h_2 s_2 - r_2 \bar{h}_1 s_2 - \bar{r}_2 h_1 \bar{s}_2 \right] + |s_2|^2 \left(|h_1|^2 + |h_2|^2\right)$$
Which is a function only of s2 only.
- Minimizing the two parts separately,we have
$$\left| \left(r_1 \bar{h}_1 + \bar{r}_2 h_2 \right) - s_1 \right|^2 + \left(-1 + |h_1|^2 + |h_2|^2\right)|s_1|^2$$
- for detecting s1,and for s2,we have
$$\left| \left(r_1 \bar{h}_2 + \bar{r}_2 h_1 \right) - s_2 \right|^2 + \left(-1 + |h_1|^2 + |h_2|^2\right)|s_2|^2 .$$

- Using the above two values,the optimum soft values of code word s1 and s2 are $(r_1\overline{h}_1 + \overline{r}_2 h_2) = \widehat{s}_1$ $(r_1\overline{h}_2 + \overline{r}_2 h_1) = \widehat{s}_2$
- Thus,we have separated signal s1 and s2 by multiplication and addition. Due to orthogonality of the code,s1is canceled out in the expression of s2and viceversa.
- The combined signal is passed through maximum likelihood detector.the transmitted symbol is determined by the maximum likelihood detector based on Euclidean distances between the combined signal and all possible transmitted symbols.

MIMO Systems Space-time block coding(STBC)

- The simplified decision rule for symbol choosing si symbol is $dist\left(\hat{s}, s_i\right) \leq dist\left(\hat{s}, s_j\right), \forall i \neq j$
- Where data (a,b) is the Euclidean distance between the signal a and b an the index j spans all possible transmitted signal.Thus,the detected symbol is the one having minimum Euclidean distance from the combined signal.

- Advantages of Alamouti's schemes are given below:
  1. No feedback is required from the receiver to transmitter.No CSI is required.
  2. There is no bandwidth expansion because its a rate-1 code.
  3. There is a complexity of decoders due to orthogonality of the code.
- Some major drawbacks of Alamouti's STBC Schemes are given below:
  1. It does not provide a code gain.
  2. Rate-1 code cannot be constructed for complex signal constellation with more than two transmitters antennas.
  3. The simple decoding rule is valid only for flat fading channel where channel gain is constant over two consecutive symbols.

Higher Order STBC Schemes

- The Alamouti scheme can be applied for a two-transmitter antenna system.Tarokh developed the scheme for STBC for three-or-four-antenna system
- For three-antenna systems,the code matrix for rate -1/2 and rate-3/4 codes can be shown

as $C_{3,1/2} = \begin{bmatrix} s_1 & s_2 & s_3 \\ -s_2 & s_1 & s_4 \\ -s_3 & s_4 & s_1 \\ -s_4 & -s_3 & s_2 \\ s_1^* & s_2^* & s_3^* \\ -s_2^* & s_1^* & s_4^* \\ -s_3^* & s_4^* & s_1^* \\ -s_4^* & -s_3^* & s_2^* \end{bmatrix}$ and $C_{3,3/4} = \begin{bmatrix} s_1 & s_2 & \frac{s_3}{\sqrt{2}} \\ -s_2^* & s_1^* & \frac{s_3}{\sqrt{2}} \\ \frac{s_3^*}{\sqrt{2}} & \frac{s_3^*}{\sqrt{2}} & \frac{(-s_1-s_1+s_2-s_2^*)}{2} \\ \frac{s_3^*}{\sqrt{2}} & -\frac{s_3^*}{\sqrt{2}} & \frac{(s_2+s_2^*+s_1-s_1^*)}{2} \end{bmatrix}$

- For the first matrix, four symbol are transmitted in a block within a eight time slots,thus,its arate-1/2 code similarly,for the second matrix ,three symbols are transmitted in four time slots in a block;hence its a rate 3/4 code.
- For four antenna systems,the codes are $C_{4,1/2} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2 & s_1 & s_4 & s_3 \\ -s_3 & s_4 & s_1 & -s_2 \\ -s_4 & -s_3 & s_2 & s_1 \\ s_1^* & s_2^* & s_3^* & s_4^* \\ -s_2^* & s_1^* & s_4^* & s_3^* \\ -s_3^* & s_4^* & s_1^* & -s_2^* \\ -s_4^* & -s_3^* & s_2^* & s_1^* \end{bmatrix}$

  and $C_{4,3/4} = \begin{bmatrix} s_1 & s_2 & \frac{s_3}{\sqrt{2}} & +\frac{s_3}{\sqrt{2}} \\ -s_2^* & s_1^* & \frac{s_3}{\sqrt{2}} & -\frac{s_3}{\sqrt{2}} \\ \frac{s_3^*}{\sqrt{2}} & \frac{s_3^*}{\sqrt{2}} & \frac{(-s_1-s_1^*+s_2-s_2^*)}{2} & \frac{(-s_2-s_2^*+s_1-s_1^*)}{2} \\ \frac{s_3^*}{\sqrt{2}} & -\frac{s_3^*}{\sqrt{2}} & \frac{(s_2+s_2^*+s_1-s_1^*)}{2} & -\frac{(s_1+s_1^*+s_2-s_2^*)}{2} \end{bmatrix}$

MIMO Systems | Space-time block coding(STBC)

- For both the cases of three- and four- antenna system,rate-3/4 code had the disadvantage of uneven power distribution among the symbol.
- Hence an improved version of the code matrix is given as

  $C_{4,3/4} = \begin{bmatrix} s_1 & s_2 & s_3 & 0 \\ -s_2^* & s_1^* & 0 & s_3 \\ -s_3^* & 0 & s_1^* & -s_2 \\ 0 & -s_3^* & s_2^* & s_1 \end{bmatrix}$ Which has equal power from all antennas in all time slots.

Quasi-orthogonal STBC(Q-STBC)

- These codes exhibit partial orthogonality and provide a part of diversity gain.An eg of such a code proposed by Hamid jafarkhani is $C_{4,1} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_3^* & -s_4^* & s_1^* & s_2^* \\ s_4 & -s_3 & -s_2 & s_1 \end{bmatrix}$
- Here,the orthogonality criterion only holds for columns(1 and 2),(1 and 3),(2 and 4),and(3 and 4).
- However,the code is full rate and still only requires linear processing at the receiver,although decoding is slightly more complex than for orthogonal STBCs
- The performances results give that q-STBC outperforms a fully orthogonal four-antenna STBC over a good range of SNRs.

STBC Concatenated With Trellis-coded Modulation

- The space-time block coding is a simple technique to achieve diversity:however,there is no significant coding gain.
- Trellis-coded modulation (TCM) is a bandwidth-efficient techniques that combines coding and modulation,without reducing the data rate.
- Concatenating STBC with TCM provides coding gain with a reasonable increases in complexity.The STBC-TCM concatenation system as shown in fig below
- First,The TCM encoder encodes the source data.Next,the encoded data is interleaved and then mapped according to the desired signal constellation.Finally,the space-time encoder encodes the data.
- At each time interval,the symbols are modulated and transmitted simultaneously over different antennas.
- At the receiver,the received data is combined according to the combining techniques described for STBC.The soft output of the combiner is sent directly to the deinterleaver.
- Finally,a TCM decoder,such as the viterbi algorithm,decodes the data.

Advantaages

The major advantages of MIMO are summarized as:

- Low power requirements and cost reduction - optimizing transmission toward the wanted user for achieves low power consumption and amplifier.
- Increased range or coverage - The array or beam forming gain is the average increase in signal power at the receiver due to a coherent combination of the signals receiver at all antenna elements.
- Improved link quality or reliability - Diversity gain is obtained by receiving independent replicas of the signal through independently fading signal components.
- Increased spectral efficiency - Increased spectral efficiency can be achieved by exploiting the spatial multiplexing gain. The spatial multiplexing creates the possibility to simultaneously transmit multiple data streams, exploiting the multiple independent dimensions so called spatial signature or MIMO channel Eigen modes.

MIMO Application in 3G wireless system and Beyond

- MIMO is improving performance of spectrum efficiency enhancement to present 3G mobile system.
- Spatial multiplexing techniques make the receivers very complex, and therefore they are typically combined with Orthogonal frequency-division multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by a multi-path channel are handled efficiently.
- MIMO-OFDM technology delivers significant performance improvements for wireless LANs, enabling them to serve existing application more cost effectively as well as making new, more demanding application possible.
- The MIMO-OFDM has redefined that trade-offs, clearly demonstrating that it can boost all three parameter simultaneously.
- While MIMO will ultimately benefit every major wireless industry, including mobile telephone, the wireless LAN industry is leading the way in exploiting MIMO innovations.
- The areas where MIMO techniques add significant value to wireless systems includes

1. Wi-Fi
2. WiMAX
3. Cellular
4. RFID
5. Mobile satellite TV
6. Satellite Radio

Wi-Fi

- Small devices with mainly indoor coverage using adaptive arrays.
- The main benefits include
  1. Range increases
  2. Interference mitigation For unlicensed band
  3. Uniform coverage
  4. Achieving higher data rates
- It achieving higher data rates makes MIMO an attractive solution.

Figure 22: Wi-Fi Network architecture

WiMAX

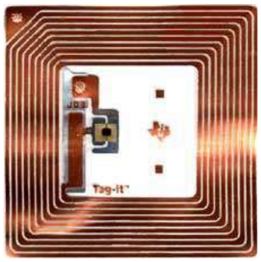
- Multi beam antennas are favoured at base stations, the base station antenna provides greater range and allows a capacity increase through spatial reuse i.e., separate beams.
- WiMAX implementations that use MIMO technology have become important.
- The use of MIMO technology improves the reception and allows for a better reach and rate of transmission. The implementation of MIMO also gives WiMAX a significant increase in spectral efficiency.

RFID

- Smart antennas, either multi beam or adaptive array can be used on readers to increase range for which a response from an RFID can be received.
- Radio frequency identification (RFID) is a wireless communication technology that allows an object to be identified remotely, which has many applications including inventory checking, access control, transport payment, electronic vehicle registration, product tracking, and secure automobile keys.
- A typical RFID system includes major components such as readers and tags.
- An RFID tag is a small electronic device which has a unique ID.

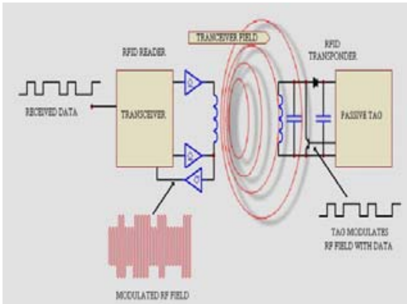
(a) RFID

(b) RFID



(c) RFID

(d) RFID



(e) RFID

Figure 23: RFID

Mobile satellite TV

- A multi beam antenna permits a low profile antenna that can track the received signal while the vehicle is in motion and also roof of a vehicle that unseen inside and outside the vehicle.

Figure 24: Mobile satellite TV

References

U. Dalal, *Wireless Communication*. Oxford University Press, 2009.