

Software Defined Radio Evolution with MIMO (Multi Input Multi Output) Technique

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Abstract

In this report, we have described MIMO (Multi Input Multi Output) Techniques in Software Defined Radio. Software defined radio (SDR) is a radio communication system which deals with implementation of software in hardware (modulators/demodulators, detectors, mixers, filters, amplifiers, etc.) MIMO technique plays a vital role in improvement of radio technology. We have gone through complete history, present arena and future improvements of MIMO techniques. MIMO is a captivating technology for wireless systems. MIMO has an excellent efficiency as well as its presence against fading and interference which is done with the use of multiple receive and multiple transmit antennas. Throughput improvement from spatial multiplexing and link budget/spatial diversity improvement are two benefits of using multiple antennas. Spatial diversity is the probability of having all antennas at bad locations is significantly lower as the number of antennas increases. Link budget improvement deals with the fact that the signals from different antennas can be combined to form a signal stronger than any of the individual signals. MIMO systems with spatial diversity gives better range for a given data rate than SISO systems at the same location. We will study further more about MIMO techniques with SDR.

Introduction

MIMO is one of the several forms of smart antenna technology. This technology has taken special place in wireless communications, because it gives significant increase in data throughput and linking range without extra bandwidth or transmits power. In software defined radio, MIMO gives splendour performance due to multiple functions. Before describing the role of MIMO with SDR, we should understand about SDR first.

1. Software Defined Radio

Software defined radio system (SDR) is a rapidly evolving technology that is receiving very much recognition and generating interest in the telecommunication industry. Radio systems are being replaced by digital radio systems for various applications in commercial, civilian and military areas. SDR technology involves with high level of hardware modules to build an open-architecture. According to Software-Defined Radio Forum (now wireless innovation) defines SDR technology as "radios that provide software control of a variety of modulation techniques, communication security functions (such as hopping), wide-band or narrow-band operation and wave form requirements of current and evolving standards over a broad frequency range."

SDR technology is being used to implement civilian radio, military, commercial and applications. Applications like

WLAN, WCDMA, GPRS, Radar, Bluetooth, etc. can be implemented using SDR technology.

2. MIMO

Multi Input Multi Output (MIMO) became an important part of modern wireless communication standards such as IEEE 802.11(Wi-Fi),4G, 3GPP Long Term Evolution, WiMAX and HSPA+. MIMO takes spectral efficiency to a new level. It offers higher rates of data throughput or improved coverage depending on the transmission technique used. This technique gives spectral efficiency which is gained by transmitting all the signals on the same channel occupying the same bandwidth. 4x4 configurations is good configurations but still it's in process, 2x2 configuration is used by many system now a days. Now MIMO is introduced in computer laptops and it's giving very good response to the field. Wi fi connection is very much good because of this technology even in bad bandwidth areas. This technology gave speed and the reception range and connection capacity improvement to the wireless communication industry. This technology is an improved and advanced technology in the field of wireless communication system which use multiple antennas for both transmission and for the reception instead of using single antenna. MISO or SIMO uses both multiple and single antenna in either reception or in the reception but MIMO uses multiple antennas in both places. This transmits more than one data streams in single channel and at exact same time. This report deals with the history, present modules and future possibilities of MIMO technique. It also deals with the models that were developed in an attempt to describe propagation characteristics for spaces diversity and smart antenna applications. Then models developed to provide the necessary channel information for MIMO applications are discussed.

2.1History

MIMO idea was firstly introduced by **A.R.Kaye** and **D.A George** long back in 1970's. In 1970-80's there were many research papers published on MIMO related applications by **Branderburg** and **Wyner** (1974) and **W. van Etten** (1975,1976), **Jack Winters** (1984) and **Jack Salz** at **Bell Laboratories** in 1986. This was firstly used in 1993 in spatial

multiplexing which was proposed by **Arogyaswami Paulraj** and **Thomas Kailath**. It was patented in 1994 and further approaches were made for MIMO. **Lospan Wireless Inc.** introduced the commercial system with the use of MIMO-OFDM technology in 2001. After this success, many wireless companies started being interested in MIMO technology and adopted this in their products. In true words, MIMO technology was not less than a revolution in the field of wireless communication system. Wireless communication is so common and used by billions of people and MIMO technology has not only helped in utilizing the available frequency but also it has increased the speed and clarity also.

3. Channel Models

Channel models were developed as an attempt to describe propagation characteristics for space diversity and smart antenna applications. These models were developed to provide the necessary channel information for MIMO applications.

3.1 Directional Channel Model

Figure1 shows three different sources of scattering that affect signal propagation between the base station and the mobile.

Scatters around the mobile station (MS): Similar height or higher than mobile, hence, the received signal at the mobile usually arrives with wide angular spread.

Scatters around the base station (BS): Generally, the energy arrives at the BS from identifiable clusters, which correspond to different propagation mechanisms.

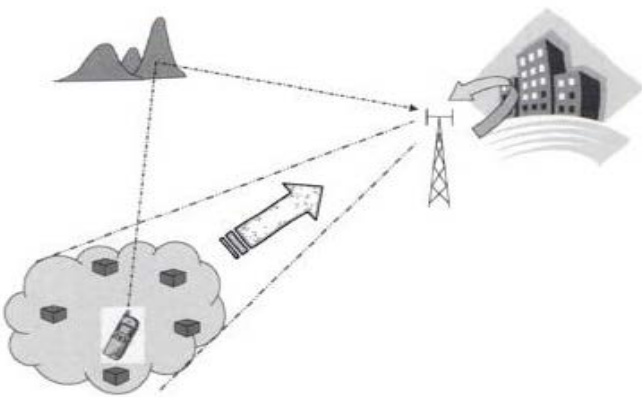


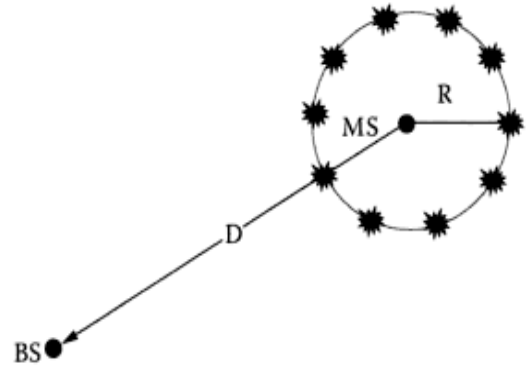
Figure1. Scattering sources for radio wave propagation modelling

Multipath from remote scatters is another possibility, e.g., in rural operational scenarios. This is contained within a

very small angular spread but contributes large delay spread.

Ring of Scatters

Figure2. One- ring- of- scatters model



This model has circular ring around the mobile which have effective scatters uniformly spaced on ring. In the one- ring- of- scatters models, MS is surrounded by scatters, while the BS is assumed to be elevated and therefore not obstructed by local scattering and no Line-of-Sight is assumed between BS and MS.

Discrete angle:

$$\theta_i = \frac{R}{D} \sin\left(\frac{2\pi}{N} i\right), i = 1, \dots, N$$

Where, N = No. of scatters, R= radius, D= distance from the base station.

3.2 Discrete Uniform Distribution Model

Lee's ring of scatters model is similar as this. Figure3 shows discrete uniform distribution of scatters.

According to this analysis, a continuous AoA distribution (Gaussian for rural - suburban environments) will underestimate the correlation that exists between the antenna array elements.

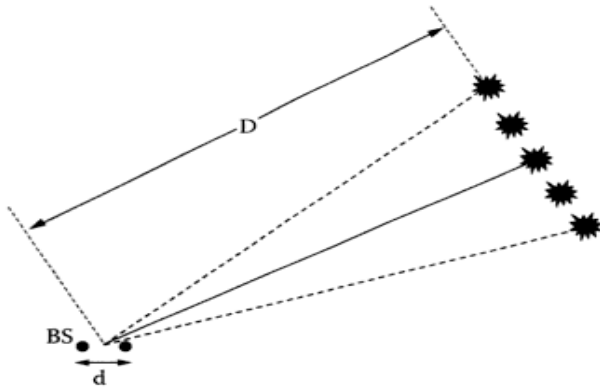


Figure3. Discrete uniform distribution of scatters

4. TYPES OF MIMO

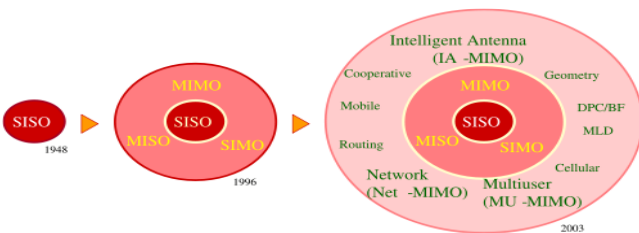


Figure4. MIMO communications

Basically there are two types of MIMO which are as follows

4.1 Multi-Antenna Types

In MIMO there is multi antenna in both Transmitter and Receiver and till now this has been developed but apart from MIMO there are few other technologies also which uses multi antenna. MISO (Multiple Input-Single Output) is a technology in which transmitter has a single antenna but receiver have multiple antennas. SIMO (Single Input-Multiple Output) is a technology in which transmitter has multiple antenna but receiver have single antenna. SISO (Single Input-Single Output) is a technology where in both transmitter and receiver have single antenna.

4.2 Multi-User Types

Multi-User MIMO more commonly known as MU-MIMO can be said an advanced set of MIMO. As the name suggests it is an advanced MIMO technology was more than one user can use the technology. Under this technology more than one user can receive the signals from same one band.

4.2.1 MIMO Technology in Laptop

Now MIMO technology has been successfully introduced in laptops. It has to be said as a revolution in the field of laptop computers. Now using WI-FI for internet in laptop can be even faster and even in bad climate or less signal areas internet can work faster and fluent.

First of all it was introduced as an external point or an adaptor to be attached to the laptop and then u can enjoy MIMO technology in your laptop, ZYXEL M-102 extreme MIMO laptop adaptor is one of the example of such adapter. It is available in the market at the price of around \$17. Going one step ahead now they have introduced laptops which have inbuilt MIMO technology in it. ASUS A6T is an example of the range of laptop which has inbuilt MIMO technology in it. It is been marketed by AIRGO and ASUS company. Even though the company is not expecting to sell lot of ASUS A6T because in normal circumstances and for daily normal laptop users inbuilt MIMO technology in their laptop will not be of very great deal of help but for people who are engaged with some high profile work were they need high speed or people who are leaving in places where they don't get good signals for their internet through Wi-Fi then I think laptops like ASUS A6T can be very useful and fruitful for them. The company is promoting this laptop by saying ASUS A6T has inbuilt Wi-Fi networking and it is the fastest. Now because of this facility people don't need to bother to purchase an external router for their Wi-Fi connection, now they don't need to bother to stick to one particular radius to get the signals rather now when computer itself is having its router u can enjoy the freedom of very good range of signals. This can be very convenient and I think this is the future of the laptop industry because one of the major function of laptop is to give access to the internet or say giving access to the internet without any cable attached and now when u have the freedom to use internet in your laptop anywhere with the help of inbuilt MIMO technology, you can say that you can utilize your laptop for using internet fully and more comfortably. No doubt it is the future of laptop industry and by the time passes laptops like ASUS A6T which have inbuilt MIMO technology will get cheaper and more affordable to the normal or average people and of course then it will become more popular and will be used more commonly. My assumption is that in future MIMO technology will be more of a necessity than anything else because the internet users around the world is increasing day by day and u need a technology with the help of which u can utilize things to its maximum and with the help of MIMO technology it is possible.

4.2.2 MIMO Technology in WIMAX

WIMAX is also a wireless technology which does different kind of function. The meaning of **WIMAX** is **WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS**. Its functions include giving wireless access to the internet just like Wi-Fi does and thus we can now say that how useful it can be with the involvement of MIMO technology in WIMAX. Other functions of WIMAX are to provide telecommunication services and data services, which is also a very related function which can be more efficient and fast with the help of MIMO technology. Providing portable connection is the main function of the WIMAX and thus we have to say that with the help of MIMO technology they can just go one step ahead in this technology. They can be faster and they can provide better service.

With the introduction of MIMO technology the WIMAX functions are now better than what they were before. The transmission rate and reach is far better than what they have before the use of the MIMO technology. The reception of signals which is one of the major factors in any wireless device has also improved in WIMAX with the help of MIMO technology.

With the use of MIMO technology, WIMAX is now better than what it was without MIMO. They are now faster than before they can do more work, there is less congestion which is again very common problem. They have overcome many problems with the help of this technology.

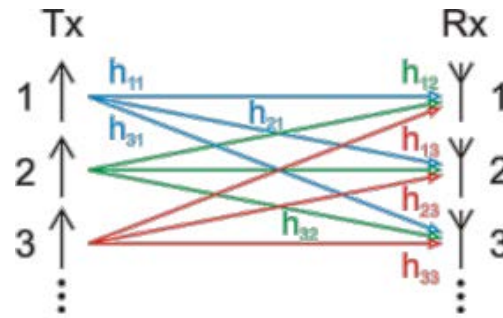
4.2.3 MIMO Technology in 4G

Now even mobile phone industry is also using MIMO technology. The new 4G mobile broadband are using MIMO technology. Nortel claim themselves one of the pioneer in the 4G industry and the reason is they are one of the fastest in the market and for that the credit should be given very much to MIMO technology which they are using to provide service to the consumer. With the help of MIMO technology they are now fast and better.

4G is for the new generation and it is the most happening thing in today's mobile phone industry and thus it has to be the best, the fastest and with the best features in it. MIMO technology provides them the best solution now they achieved what they wanted.

5. Mathematical Description

MIMO includes multiple antennas on both receiver and transmitter. Matrix channel procedure is used to transmit the signals which have all the receiver paths.



MIMO channel Model

Then at receiver end, signal vectors are received by the receiver antennas and decode the signal vectors into its real image.

MIMO system modelling is done as

$$Y = Hx + n$$

Where, y = receiver vector, x = transmit vector, n = noise vector and H = channel matrix.

Then total transmitted power available per symbol period be P . Then,

$$C = \log_2 (I_M + HQH^H) b/x/Hz$$

Where $Q = E \{xx^H\}$ and $\text{trace}(Q) < P$ according to our power constraint

Then,

$$C_{EP} = \log_2 [I_M + (P/M_T) HH^H] b/x/Hz$$

Foschini and Telatar both demonstrated that as M_T and M_R grow,

$$C_{EP} = \min(M_T, M_R) \log_2 (P/M_T) + \text{constant } b/x/Hz$$

M_T = Transmitter, M_R = Receiver, C_{EP} = Channel Capacity.

6. MIMO Functions

MIMO can be functioned in main three functions which are shown as further **precoding**, **spatial multiplexing**, or **SM**, and **diversity coding**.

6.1 Precoding

This multi-layer beam is formed in all spatial processing at the transmitter end.

The same signal is emitted from all the transmit antennas with appropriate gain with maximization at receiver end.

While having multiple antennas, receiver antenna can't be maximizing the signal level and precoding is used at this level.

6.2 Spatial multiplexing

It is done with the MIMO antenna properties. It deals with the partitioning of high rate signal into low rate signals and each signal has the same frequency while transmitted from different antennas. This is a very powerful technique for channel capacity increment at high SNR. Lesser no. of antennas on any of the side (transmitter or receiver) or on the both sides helps to limit the maximum number of spatial signals (streams).

6.3 Diversity Coding

Diversity coding is used when transmitter has no signal in contact with it. In these methods, space time coding is used for signal coding while transmitted from the transmitter. It deals with the single transmission of the signal. Signal is transmitted from all the antennas one by one. In this technology, no beam forming or array gain is done because of empty channel.

7. MIMO Applications

MIMO is performing a vital role in Software Defined Radio (Wireless Industry). Receiving signals is the complex way while performing spatial multiplexing. To overcome this problem, these are combined with OFDM or OFDMA (Orthogonal frequency division multiplexing or Orthogonal frequency division multiple access) modulation. This is done with multi path channel with handled efficiency. IEEE 802.11n (Wi-Fi) standard was introduced in Oct. 2009 which is an extension to IEEE 802.16e which is done with MIMO-OFDMA combination. Mobile standards are also deals with MIMO operations. 3GPP and 3GPP2 are also one of the applications for MIMO.

Cellular environment is fully supported by MIMO technique as it includes IST-MASCOT to give advanced version of MIMO techniques. Multi user MIMO is the best example for this. MIMO technology is highly being used in laptops for Wi-Fi connection. This can be used in non-wireless communications such as in home networking. It obeys power line communications to exchange signals through AC wires.

8. Conclusion

MIMO technology has been a revolution in wireless communication industry and no industry in this field is left not utilizing the benefits of MIMO technology. MIMO

technology has made the existent wireless technology fast and more efficient. More and more people in today's world is getting attracted towards wireless products. The sale of laptops, mobile phones etc. are at all time high and it's not going to reduce but only increase in future. People want technology to grow and they want to experience something new every time. MIMO technology is the technology for today's world, it fulfil what today people want. There is no doubt that in future something better technology will overtake MIMO

technology but for now in the industry of wireless communication MIMO is the supreme and is a revolution.

MIMO technology has been not only a great satisfier but also it has helped in removing lot of prevailing problems, especially because of the number of users increasing every day. It has helped reduce the congestion and still to be faster than any other technology. I have no doubt that in near future all wireless products will have MIMO technology in it. Though now it might cost a bit higher than normal but sooner it will reduce.

It is how it goes new technology are always expensive at first but later it will be affordable to everyone. As I have mentioned in laptops it is apt in all other wireless devises as well.

In management we learn that if you want to earn maximum profit you have to utilize your recourses fully and that's what MIMO technology has helped as to achieve, it has helped as to use our resources fully and efficiently and while doing that It has not reduced the quality but rather the quality has been improved better than what it was.

Now the technology is faster than before, it works more efficiently in difficult places or places were wireless signals are hard to get. Definitely it's been a revolution in the field of warless technology and I'm sure sooner or later all forms to products related to this field will utilize the valuable benefits of MIMO technology.

9. MIMO Future Prediction

The new MIMO technology is rapidly growing and I think this technology has a bright future. There are several new elements getting added to the MIMO technology like the next generation MIMO's are combining multiple antennas along with double spectrum architecture, thereby achieving raw data to go up to 600 Mbps. The special multiplexing in MIMO technology helps to achieve higher throughput i.e. when more than one stream is transmitted at the same time from a transmitter to the receiver it develops spatial division multiplexing and these several streams are also

transmitted simultaneously using the same time and frequency which ultimately helps to achieve a boost in the spectral efficiency.

MIMO technology is used in the Third generation partnership projects like the 3GPP & 3GPP2 in order to help in the evolution of new cdma2000 systems and Universal Mobile Telecommunications Systems. The future wireless systems with the help of MIMO technology can be made to obtain high speeds of data downlink solution by integrating with the orthogonal frequency domain multiplexing air interface which helped in evolution of the 3G systems. Other revolutionary ideas are RADAR beam forming, intelligent spatial processing and also virtual antenna MIMO. The multi user MIMO is another process which will allow multiple users in spatially distributed resources.

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11. Biography

Author became member of IET (Institute of Engineering and Technology), England & Wales in 2011. Born in 1987 in India, completed Bachelor in Engineering from Advanced Institute of Technology and Management, Palwal. Currently Pursuing Masters in Embedded Intelligent System at University of Hertfordshire, United Kingdom. Appin Technologies, UK certified embedded engineer and very much interested in embedded robotics. Have done projects on GSM robot and RISC processor. Currently studying fuzzy logic for robot control.



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