Principles of Modern CDMA/MIMO/OFDM Wireless Communications

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Lecture – 34
Multiple Input Multiple Output (MIMO) Systems

Hello, welcome to another module in this massive open online course on the principles of CDMA, MIMO, OFDM wireless communication systems. Today we are going to start discussion on a new topic and a very interesting and a very key topic which is termed as MIMO.

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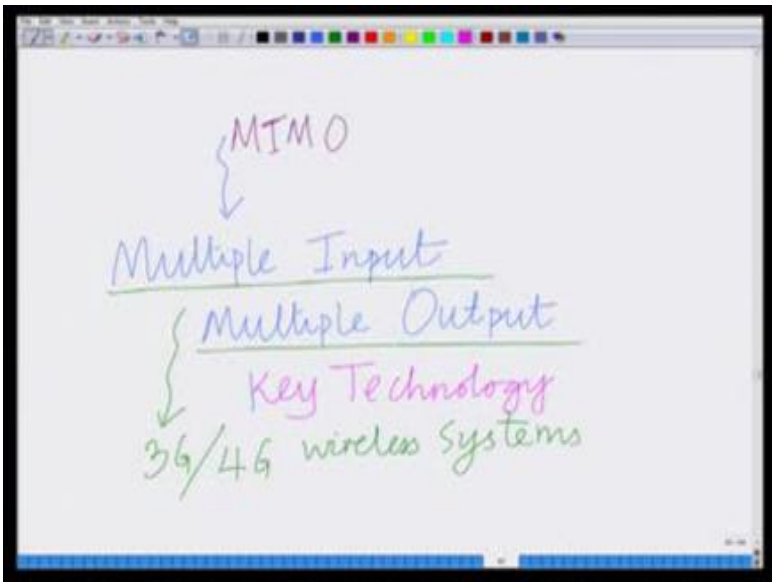

MIMO is a very important which stands for Multiple Input Multiple Output. This MIMO which stands for Multiple Input Multiple Output wireless communication system is a key and in fact it is one of the latest and one of the most important milestones in the development of wireless technologies and it is a key one of the critical technologies that is used in 3G and 4G wireless communication systems. MIMO is extensively used in 3G and 4G wireless systems in fact it is a very prominent and a very important it is a key technology in 3G and 4G wireless communication system the reason being;

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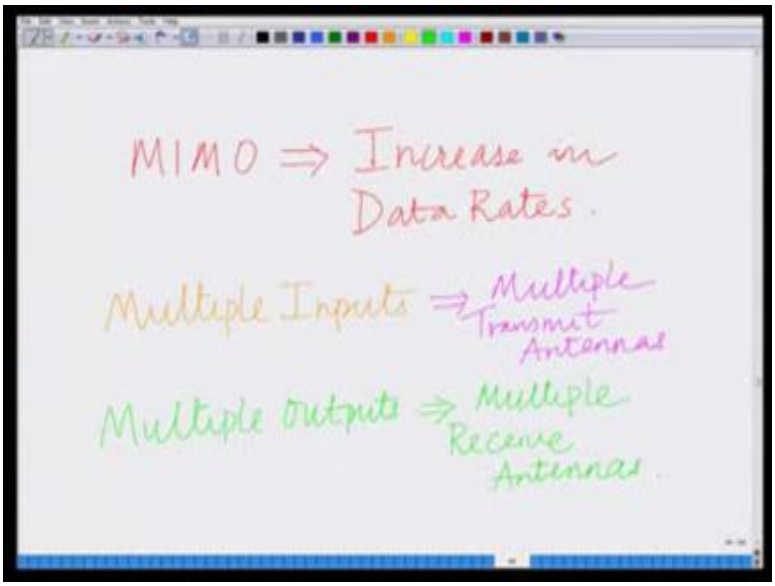

MIMO leads to an increase in the data rate; that is the MIMO system that is your Multiple Input Multiple Output wireless communication based systems leads to a significant increase in the data rates that are possible in wireless communication systems and therefore, this is a very important technology in 3G, 4G wireless communication systems since these 3G, 4G systems are based on very high data rates. They enable transmission of very high data rates over the wireless channel and this module starting with this module will explore this area of MIMO or Multiple Input Multiple Output wireless communication systems in great detail.

Now let us start with this basic idea of MIMO. MIMO as you know the name itself says MIMO stands for Multiple Inputs and what are these Multiple Inputs? They are Multiple Transmit Antennas on which multiple inputs are provided to the wireless system and what are the Multiple Outputs implies multiple receive. The multiple outputs are available on the multiple receive end. So, a Multiple Input Multiple Output wireless system is simply a combination of Multiple Transmit Antennas at the transmitter in which multiple inputs are provided to the wireless channel and Multiple Receive Antennas at the receiver in which multiple elements or multiple measurements or multiple samples are received as the output of the wireless communication channel. So, together Multiple Transmit Antennas at the transmitter and Multiple Receive Antennas at the receiver constitute or make a MIMO system Multiple Input Multiple Output wireless communication system.

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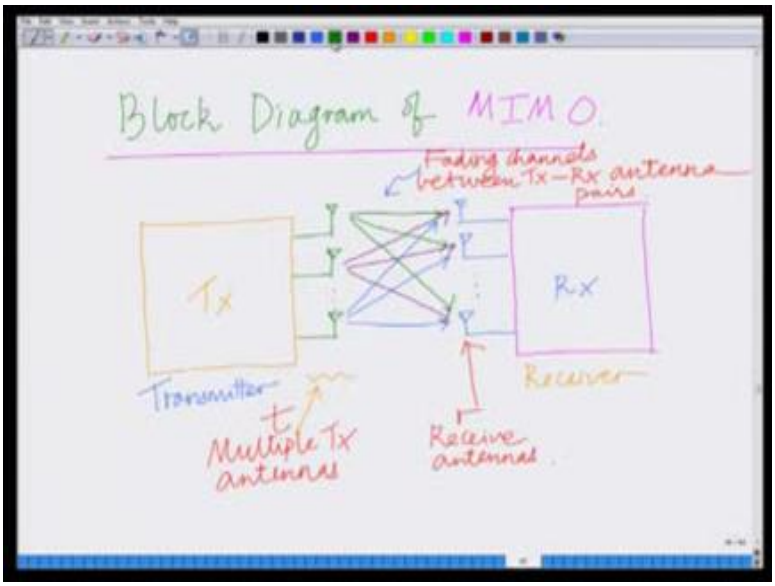

Now what we are going to look at is let us look at a simple block diagram MIMO channel. So, I have my transmitter which has Multiple Transmit Antennas and I have a receiver which has; I have a transmitter and this is my receiver and there are Multiple Transmit Antennas. At the transmitter in particular let us say we have t transmit antennas and we have multiple antennas at the receiver that is r; receive antennas at the receiver and there is a fading channel co efficient between each transmitting antenna and each receive antenna.

In particular a MIMO system in particular a Multiple Input Multiple Output wireless communication system is a collection of a large number of Fading Channels one between each transmit antenna and each receive antenna pair. So, between each combination of transmit and receive antenna there is a fading channel and the MIMO system is the collection or is the combination of large number of Fading Channels alright. This MIMO system comprises of a large number of Fading Channels. So, Fading Channels between transmit and receive antenna pairs and as we have already seen when we have multiple antennas.

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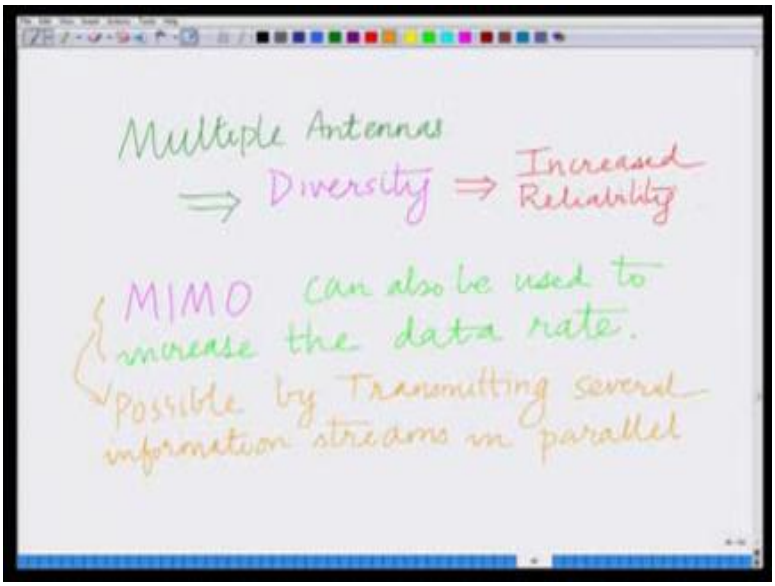

For instance when we have multiple antennas at the receiver we have already seen that leads to Increased Reliability through the Diversity principle right. Multiple antenna leads to Diversity which means it leads to an Increased Reliability. Multiple antennas for instance multiple antennas at the receiver lead to receive Diversity which leads to an Increased Reliability we have already seen the Bit Error Rate performance with multiple antennas. We have seen the Diversity gain the Diversity order; however, when you have multiple antennas at both the transmitter and receiver the behavior is something slightly different in addition to Diversity it is also possible to transmit at a much higher data rate this is known as spatial multiplexing.

So, with multiple transmit and receive antennas MIMO can also be used to increase not only the reliability, but also the data rate in these communication system and this is possible by transmitting several information in parallel. What is happening in a MIMO system or what is possible in a MIMO system is the parallel transmission of several information streams between the transmitter and the receiver and this is known as Spatial Multiplexing.

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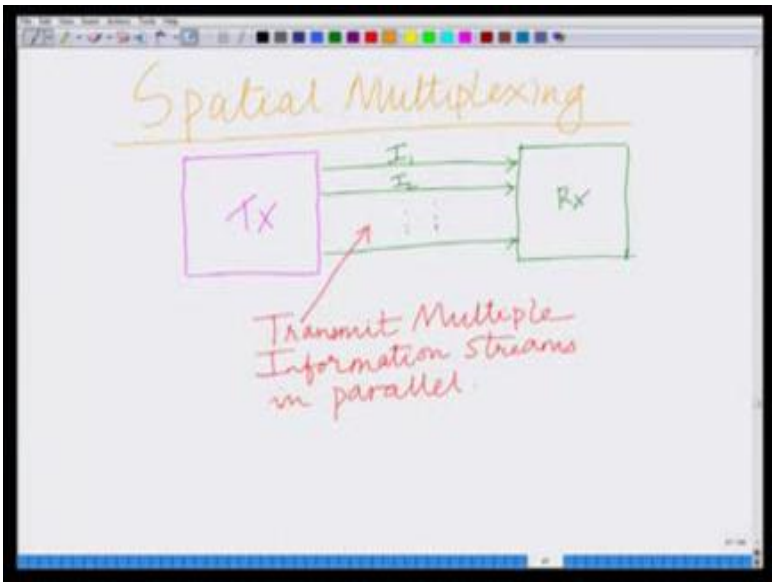

In a MIMO system; what we have in a MIMO system that is if I have the transmitter and I have my receiver I have the receiver and where previously I could only transmit one information stream now I can transmit multiple information streams I_1, I_2 and so on. What I can do in a MIMO system is I can transmit multiple information streams I can transmit multiple information streams in parallel and this property which is a very key property of MIMO systems; this is termed as Spatial; this property of MIMO systems where we transmitting multiple information streams in parallel between the transmitter and receiver is termed as Spatial Multiplexing that is multiplexing the space dimension multiplexing in the space dimension that is we are using the space not frequency that is rather than frequency or time we are using space that is the radio frequency channel to simultaneously multiplex several parallel streams of information or simultaneously transmit several streams of information in a parallel fashion there by increasing the data rate many times and this principle is termed as spatial multiplexing which is a very important principle of Multiple Input Multiple Output wireless communication systems.

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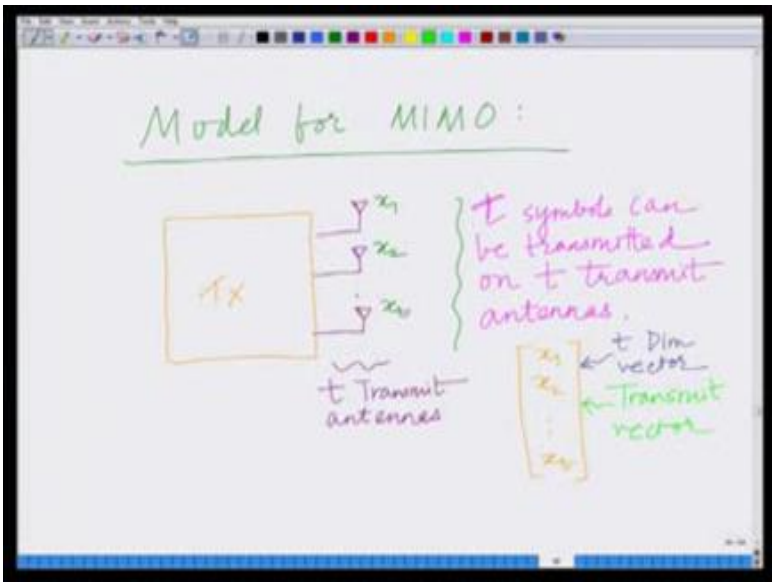

Now what we want to do is we want to develop a model for MIMO system. So, our next task is basically to develop a model for our MIMO system and naturally what we have in a MIMO system is we have a transmitter with Multiple Transmit Antennas that is we said we have t transmit antennas; I can transmit t symbols on this t transmit antennas; I am going to denote these by x_1, x_2 so on up to x_t; since I have t transmit antennas; t symbols can be transmitted. What we are saying is basically t symbols can be transmitted on t transmit antennas. We are denoting these t symbols x_1, x_2 so on up to x_t similarly we can stack these t symbols as a vector that is the vector x_1, x_2 so on up to $x_t$naturally this will be a t dimensional vector this is known as the Transmit vector in the MIMO system. So, I can stack these t symbols as a vector x_1, x_2 so on up to x_t and this is naturally what we are saying is this is a t dimensional vector and this is termed as the Transmit vector in the MIMO system.

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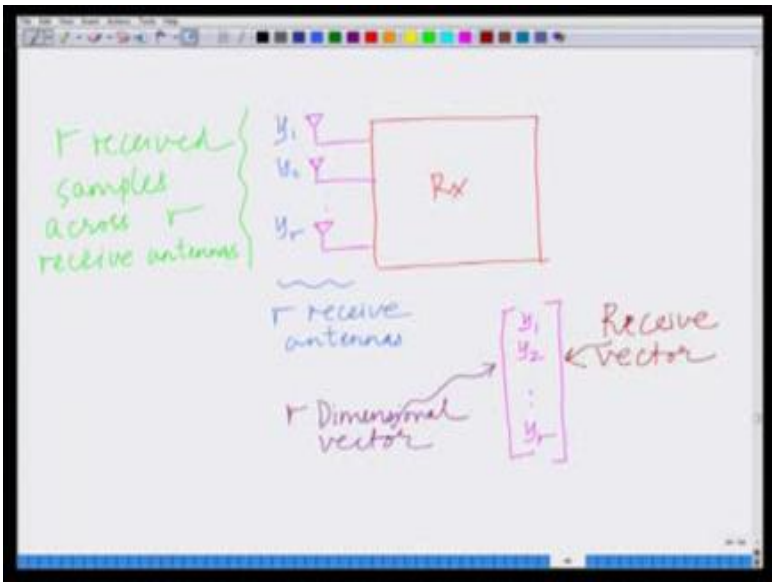

Now, let us turn our attention to the receiver. At the receiver what do we have at the receiver? at the receiver we have r receive antennas. I can receive r samples; I am going to denote these by y_1, y_2 so on up to y_r. What are these? These are basically the r received samples across the r receive across the r receive antennas and once again I can stack these as a vector that is I can stack these received samples y_1, y_2 so on up to y_r as a vector; naturally this is again going to be an r dimensional vector and this is known as in the MIMO system this is known as the receive vector of the MIMO system. So, what we have so far is we have Transmit vector which comprises of the symbols x_1, x_2 so on up to x_t which are the t symbols that are transmitted on the t transmit antenna since this is a t dimensional vector we have the receive vector which is y_1, y_2 so on up to y_r which are the r samples received on the r receive antennas. Hence this is an r dimensional vector and now what we have is basically we have to relate this transmit.

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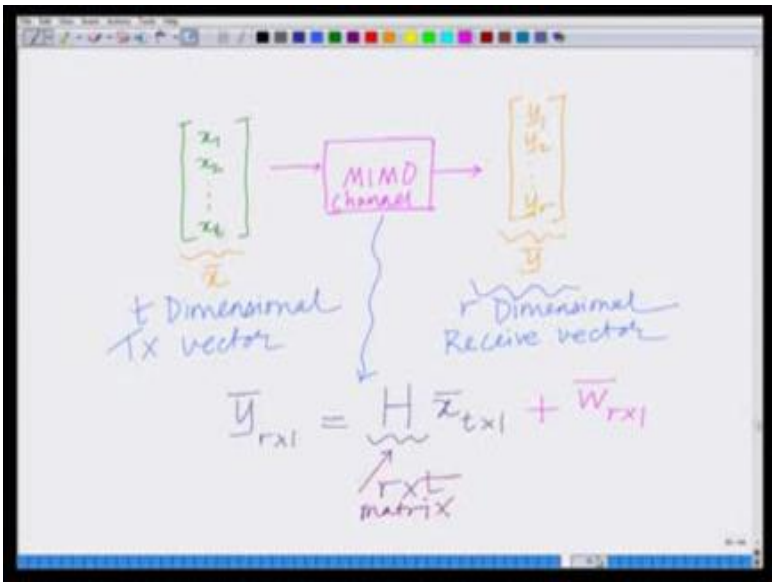

I have my Transmit vector is passing through my MIMO channel and this is giving rise to my received vector which is r dimensional. This is my t dimensional. Let me denote this is by $\bar{x}$, let me denote this by $\bar{y}$, this is my t dimensional Transmit vector and this is my r dimensional receive vector. Now, therefore, input to the wireless channel is a t dimensional Transmit vector, the output from the wireless channel is the r dimensional receive vector. Therefore, the MIMO channel must be something that transforms this t dimensional vector into an r dimensional vector and that therefore, we know that such a transformation is nothing, but a matrix transformation takes an input as a t dimensional vector and it is output is an r dimensional vector. Therefore, I can model this MIMO channel as an r X t matrix.

So, my MIMO channel is basically something that has $\bar{y}$ which is an r dimensional vector equals H times $\bar{x}$ which is a t dimensional vector. Naturally this channel matrix of the MIMO channel must be an r X t matrix which transforms this t dimensional input vector into the r dimensional output vector; plus of course, in the presence of noise and this noise is again an r dimensional output vector.

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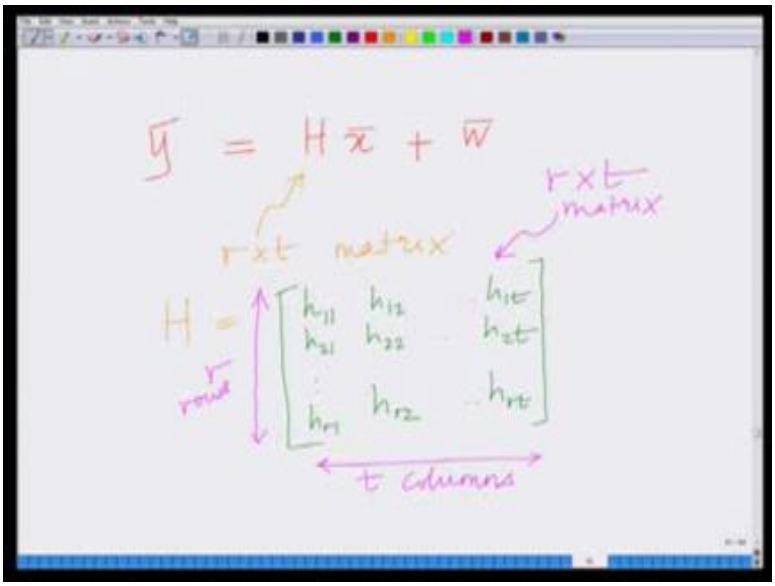

Let me write this again since this is the key equation for the MIMO channel; I have

$$\bar{y} = H\,\bar{x} + \bar{w}$$

H is an r X t matrix which means my H can be represented as

$$H = \begin{pmatrix} h_{11} & \cdots & h_{1t} \\ \vdots & \ddots & \vdots \\ h_{r1} & \cdots & h_{rt} \end{pmatrix}$$

The last row will be h_{r1}, h_{r2} so on up to h_{rt} and therefore this is also known as my MIMO channel matrix. This has basically r rows; this is an r cross t matrix so this r rows and t columns. So, basically this is an r cross t. My MIMO channel matrix is an r cross t matrix where r is the number of receive antennas, t is the number of transmit antennas; basically it means that this has r rows one corresponding to each receive antenna and t columns one corresponding to each transmit antenna and the coefficient h_{ij}, let us look at the coefficient h_{ij}.

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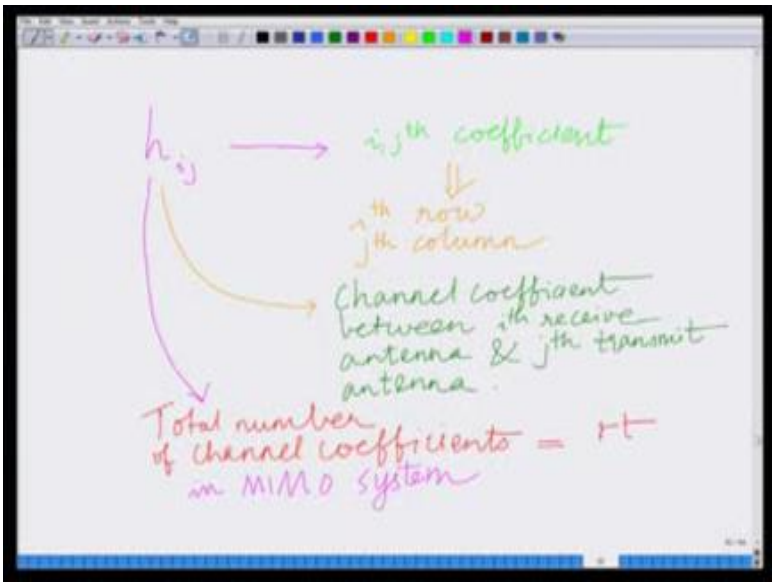

So, h_{ij} what is this? This is the i, j th coefficient. I, j th coefficient means this is the i th row, j th column. Therefore, this h i j corresponds to is nothing but the channel coefficient between i th receive antenna and the j th transmit antenna. So, h_{ij} which corresponds to the channel coefficient in the i th row and the j th column is basically the channel coefficient between the i th receive antenna and the j th transmit antenna; as we said there is one channel coefficient between each pair of transmit and receive antennas alright and this is an r X t channel matrix which means that there are r X t channel coefficients.

Total number of channel coefficients in this system MIMO system equals the product of r into t or simply I can denote this as r X t that is the total number of channel coefficients in the MIMO this is the total number of channel coefficients in the MIMO system that is r times t where r is the number of receive antennas and t is the number of transmit antennas and h_{ij} is the channel coefficient between the i th receive antenna and t th transmit antenna.

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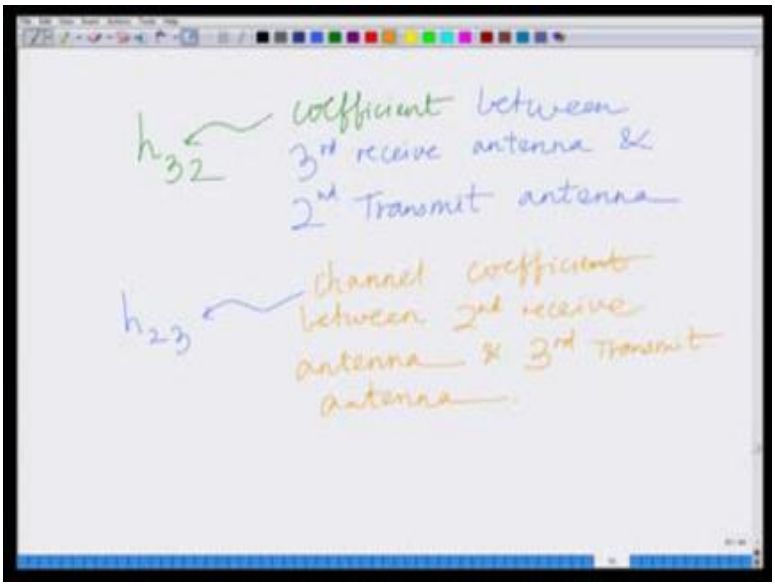

For instance let us take a simple example if I look at h_{32}; this is the channel coefficient between third receive antenna and second transmit antenna and on the other hand if you look at h_{23}; this is the channel coefficient between the second receive antenna and third transmit antenna; what we have is we have h_{32} is a channel coefficient between the third receive antenna and second transmit antennah_{23} is the channel coefficient between the second receive antenna and the third transmit antenna and in general h_{ij} is the channel coefficient between the i th receive antenna and the t th transmit antenna and this is the MIMO channel matrix. So, this models the MIMO channel matrix H which has r rows and t columns and a total of r X t the product of r into t channel coefficients where r is the number of receive antennas and t is the number of transmit antennas.

So, let us stop this model here; this model has introduced the basic notion of a MIMO system, the basic motivation behind a MIMO system and a simple model for the Transmit vector, the receive vector and also the channel matrix in this MIMO system. So, we will stop this module here and look at other aspects of MIMO systems in subsequent modules.

Thank you very much.