Principles of Modern CDMA/ MIMO/ OFDM Wireless Communications
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Lecture – 45
Orthogonal Frequency Division Multiplexing (OFDM)

Hello. Welcome to another module in this massive open online course on the principles of CDMA, MIMO, and OFDM Wireless Communication Systems. So in the previous module, we have seen various aspects of MIMO communication systems the properties, the behavior and the various transmissions schemes and the analysis related to MIMO communication systems, let us now in this module start with a new technology that is OFDM.

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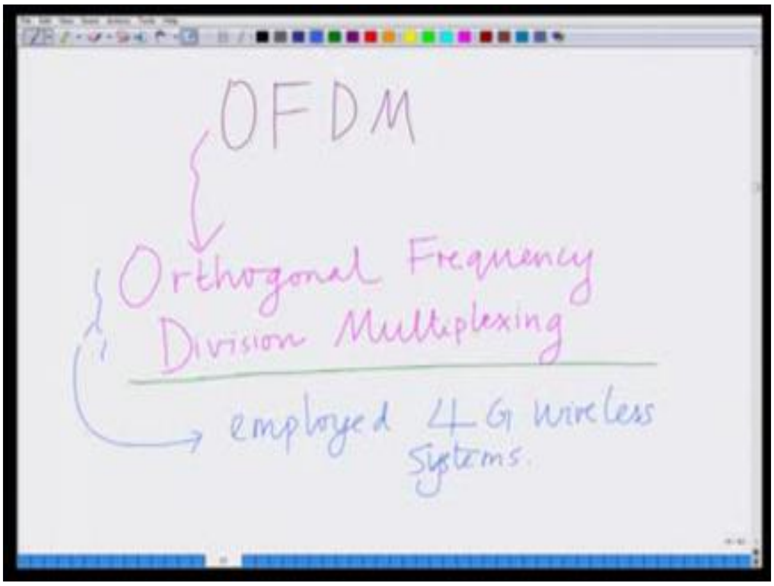

So, what we are going to look at in this module is that is; starting with this module is introduction to a new technology and in fact, a very prominent and a very key technology that is OFDM which stands for Orthogonal Frequency Division Multiplexing. So, we are going to start with OFDM which stands for Orthogonal Frequency Division Multiplexing and this is a key standard because OFDM is employed in 4G wireless system.

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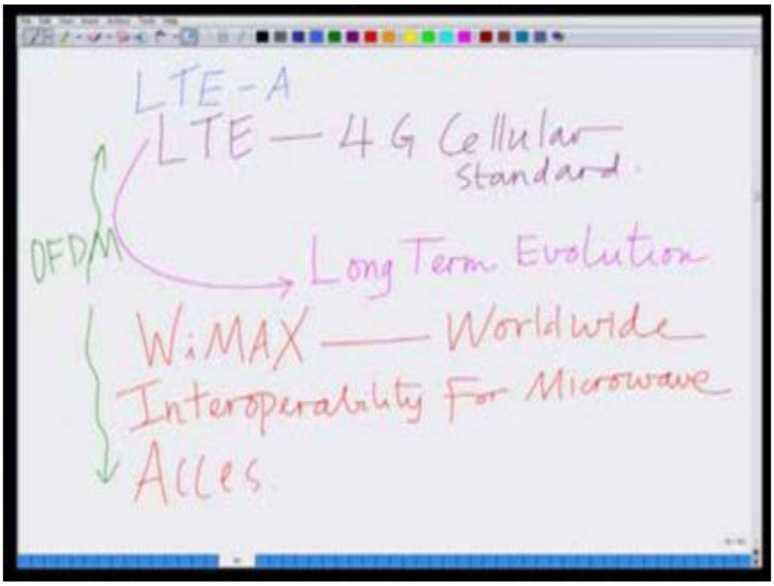

So this is a key technology which is employed in 4G wireless that is the fourth generation wireless systems such as if we look at for instance LTE, this is a 4 g cellular standard; this is a fourth generation cellular standard and this stands for long term evolution correct, we have already seen this. Another 4G or 3.75 G standard is WiMAX; as we have seen this stands for, Worldwide Interoperability for Microwave Access that is worldwide interoperability for microwave access.

So, we have LTE which is long term evolution which is a 4G cellular standard and another competing standard which is WiMAX; Worldwide Interoperability for Microwave Access both of these are based on; these are dominant standards and both of these are based on OFDM, so if you look at the cellular world both of these are based on OFDM, similarly LTE advanced that is denoted by LTE A.

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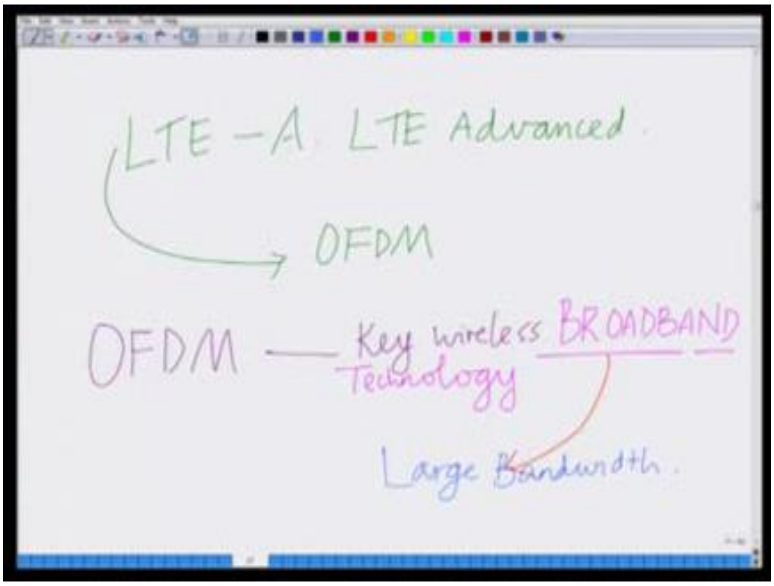

So, if we look at LTE A, that is LTE advanced which stands for LTE advanced, this is also based on OFDM which is Orthogonal Frequency Division Multiplex. So, what is the important aspect of OFDM? OFDM is a key broad band wireless technology. So, this is a key wireless and we can emphasis broad band; key wireless broad band technology and by broad band, we mean a system basically a wireless system which has a large band width, so this wireless systems supports a large.

So, what are we looking at; we are looking at OFDM which is Orthogonal Frequency Division Multiplexing which is a key wireless technology and not just that it is a broad band technology, so it operates on a huge band width, it operates on a large or a very wide band. For instance, if we look at a GSM system, a GSM system has a band width of about 200 kilohertz, but an OFDM system can have a band width up to 20 megahertz. So, this is several times that of; for instance is about 100 times that of a GSM system. So, it operates over a large band width, it is a broad band system since it has a large band width therefore, naturally the data rate is higher and these high data rates are used in 3G and 4 G in fact, 4 G wireless systems to enable data rates up to 100s or even more than 100 megabit per second about 500 megabit per second or even up to 1 gigabit per second.

So, LTE and LTE advanced which are based OFDM and operate thereby are broad band wireless cellular system can support, can enable a very high data rate of the order of 100s of megabits per second, this is possible because of OFDM which stands for Orthogonal Frequency Division Multiplexing and not simply cellular standard.

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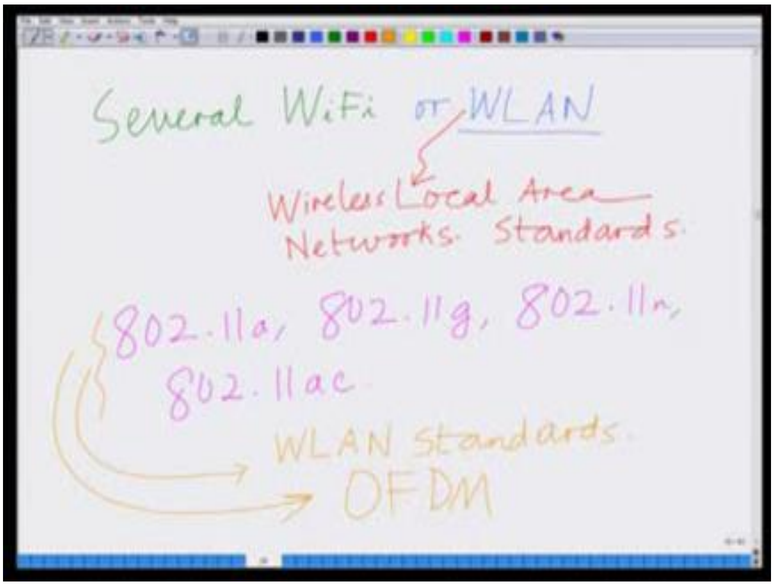

But if we look at WiFi or wireless lan standards, so several WiFi or wireless lan that is wireless local area network standards, so these are wireless. So, WiFi or wireless local area WLAN; Wireless Local Area Network standards, so these WLAN standards, what are the various WLAN standards, for instance 802.11a, 802.11g, 802.11n and there more recent 802.11a c. If you look at all of these, these are the various IEEE WLAN standard and these are based on these enable high data rates because these are based on OFDM or Orthogonal Frequency Division Multiplexing.

So, several wireless LAN standards such as 802.11 g, 802.11 a, 802.11 n, 802.11 a c which are the WiFi standards (Refer Time: 07:38) these are known as WiFi standards while technically these are wireless LAN, wireless local area network standard; these are also based on OFDM. So, OFDM is a key wireless technology which is used in several cellular, 4 G cellular and several wireless LAN standard because it is a broad band wireless technology which enables high data rates. At the same time it is practically it has a low complexity of a implicating, it implements it enables easy implementation of these broad band wireless communication systems. So, let us look at the basic principles of OFDM, so what is the basic principle behind OFDM.

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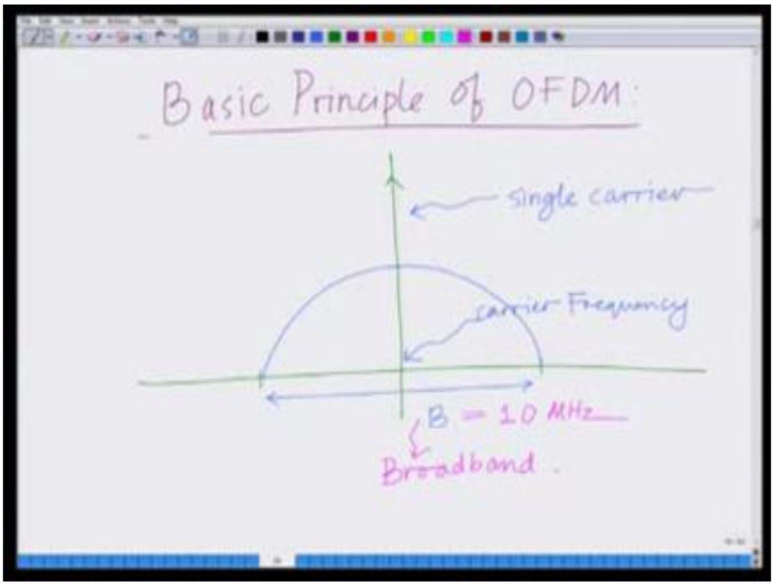

And the basic principle behind OFDM can be explained as follows, for instance if you look at a typical communication system, a communication system as you all know has a certain band width which is B, I have a communication system over a band width which is b and I have a single carrier; I have a carrier. So, in a communication system I have a band width and I have a single carrier placed at the center of the band width at the carrier frequency correct. So, let us say this is our carrier frequency, I have a single carrier let us take a simple example, let us say my band width is 10 megahertz, so this is a broad band system of bandwidth 10 megahertz.

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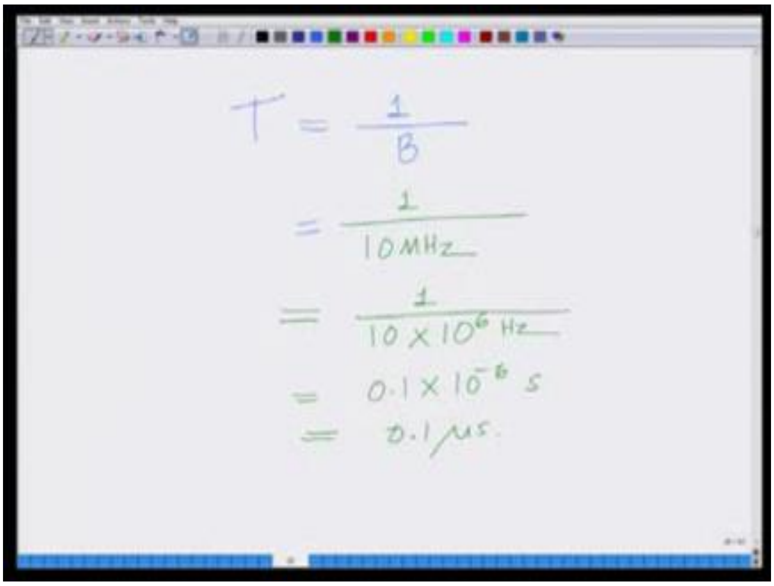

Now therefore, if you are performing communication, the communication system that is implemented over this band width has a symbol time T is equal to

$$T = \frac{1}{B} = \frac{1}{10\,MHz} = \frac{1}{10 \, x \, 10^{6}} = 0.1 \text{ x } 10^{-6} = 0.1\mu s$$

So, therefore we have a symbol time, that is what we are saying is; we are considering a communication system which has a band width of 10 megahertz. In this band width B which is 10 megahertz, the symbol time is $T = \frac{1}{B}$. Therefore, the symbol time is 1 over 10 megahertz which is 0.1 micro second.

So, what we are saying is for communication over this band width of 10 megahertz, the symbol time is 0.1 micro seconds.

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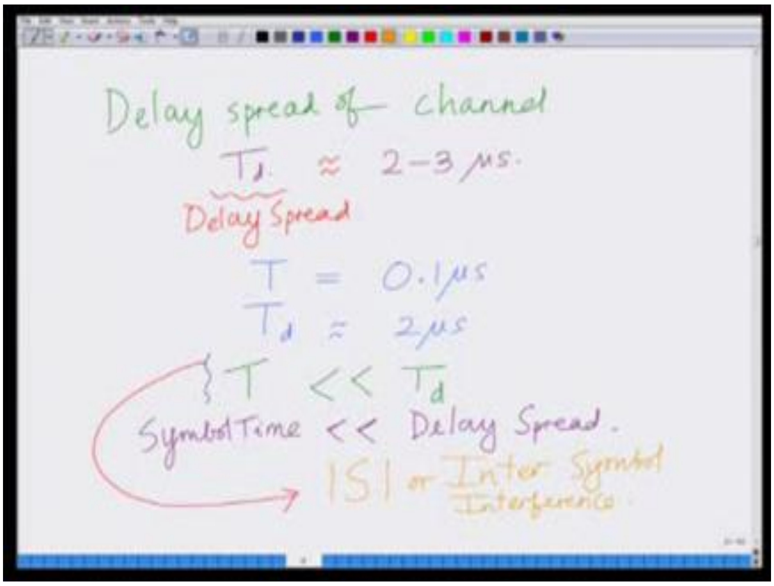

However, you might remember from the initial modules that is, the delay spread if we look at a typical outdoor channel; the delay spread of the wireless channel T_d is approximately 2 to 3 micro seconds that is 2 to 3 micro seconds. So, if I look at T_d where T_d is my delay spread, is of the order of 2 to 3 micro seconds which means now if I look at the relation between this symbol time. Now let us look at this our symbol time is 0.1 micro seconds, our delay spread is approximately let us say 2 micro seconds.

Therefore the symbol time T is much less than the delay spread T_d,

$T \ll T_d$

What we are observing is the symbol time is 0.1 micro second; the delay spread is about 2 micro second. So, the delay spread is about 20 times larger than the symbol time correct which means now you might also remember from the characteristics of the wireless channel that when this delay spread is larger than the symbol time, we have inter symbol interference of this, what does this lead to? This leads to a problem what is the problem, this leads to ISI.

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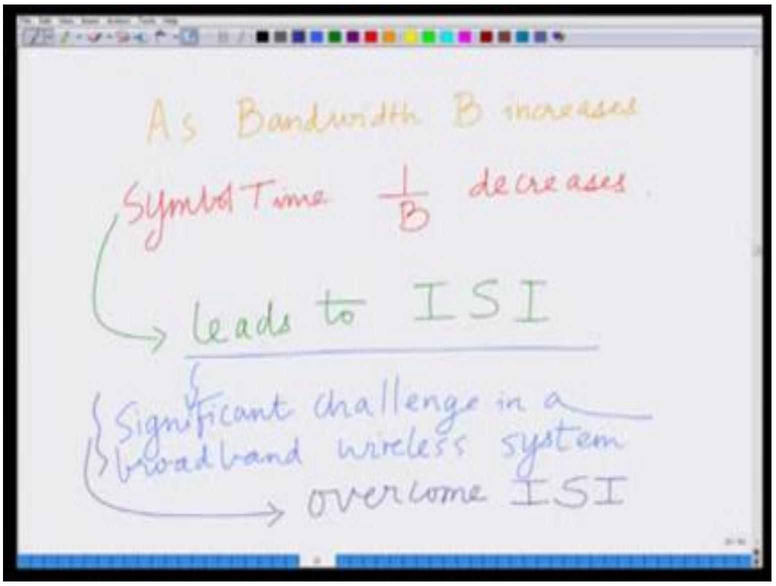

So what we are observing is as the band width B increases, what happens is our symbol time $\frac{1}{B}$ decreases and therefore, as the band you saw the systems becomes more and more broad band that is the band width B is increasing is becoming larger and larger, the symbol time 1 over B is becoming smaller and smaller. Now since this symbol time is becoming smaller, it is going to become lower than the delay spread of the channel; once it is lower than the delay spread of the channel, this results in inter symbol interference and when you have interference; this leads to a degradation or this leads to a loss of performance of the wireless communication system.

So, the inter symbol interference resulting in a broad band wireless communication system leads to a performance or leads to a degradation of the performance and therefore, this is a significant challenge, this is the significant problem and addressing this problem of inter symbol interference is a significant challenge in a broad band wireless communication system. So, this leads to inter symbol interference; leads to ISI as we said ISI stands for inter symbol interference and this is a significant challenge in a broad band wireless system.

So, how to overcome ISI, so our main problem is to overcome the inter symbol interference. What is the challenge? The challenge is to overcome the inter symbol interference, the challenge is basically because of this small symbol time that is as the band width is increasing, the symbol time 1 over B is decreasing which is leading to inter symbol interference. The challenge is to overcome this inter symbol interference and what is the principle, what is the method or the means to overcome this inter symbol interference and the scheme is simple, how to overcome the inter symbol interference.

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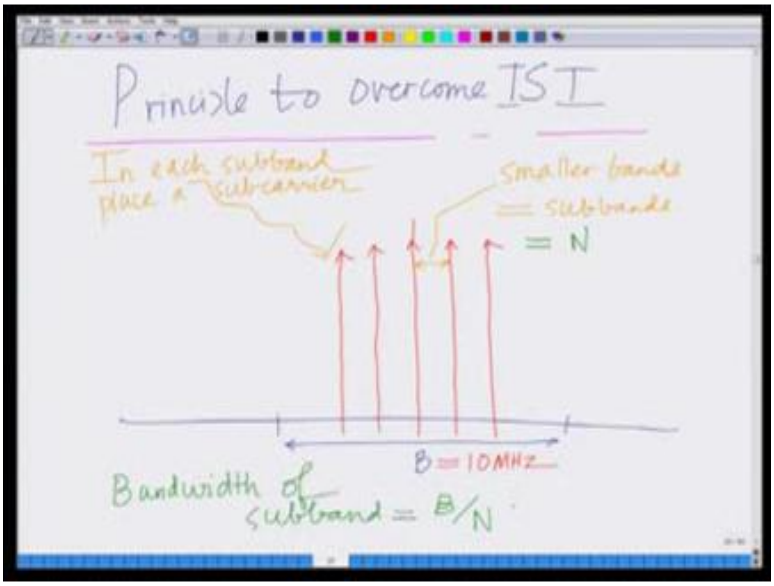

So, and the principle to overcome that is to avoid inter symbol interference, realize that the inter symbol interference is arising in the first place because of the large band width. So what we do is when we have a large band width, instead of using the entire band width at once, what we do is we use it piece meal, what we do is we take this large band width B and we split it into smaller bands or we split it into what are known as sub bands.

So, I have a large band width which I said is B = 10 megahertz, I am splitting this into smaller bands, so I am splitting this into each smaller bands which are termed as sub bands, so previously we had a single carrier; now we will have multiple carriers one in each sub band, this is termed as a sub carriers. So we will have smaller sub bands, in each sub band; place a sub, place a sub carrier. Now if you look at this, if I let us say have n sub bands, so I am saying smaller sub bands; let us say n right then band width of each sub band is equal to B by n.

So, what we are doing is; we are taking a large band width B, we are diving it into N sub band, so the band width of each sub band is $\frac{B}{N}$.

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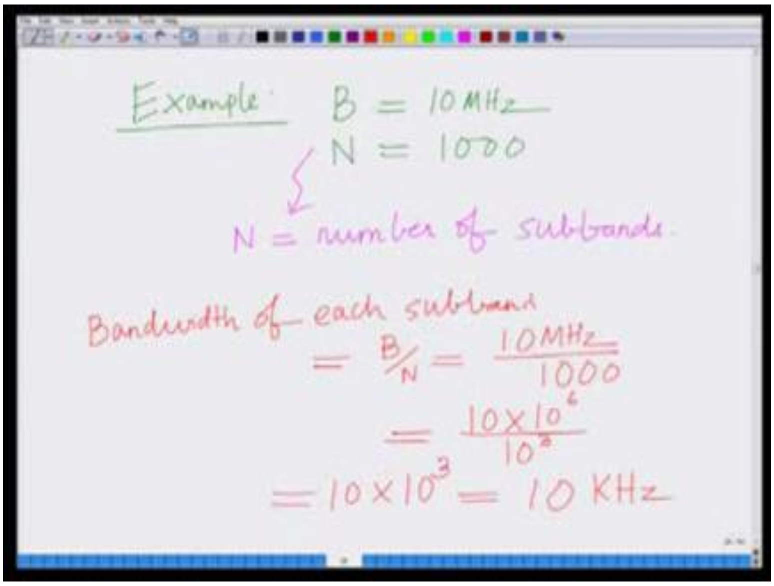

Let us take a simple example, for example, B equals let us say 10 megahertz and N = 1000 what is N; N is basically equal to the number of sub bands equals to 1000, then the band width per sub band of each sub band;

$$= \frac{B}{N} = \frac{10\ MHz}{1000} = 10\ \text{KHz}$$

Now if you look at the symbol time in each sub band.

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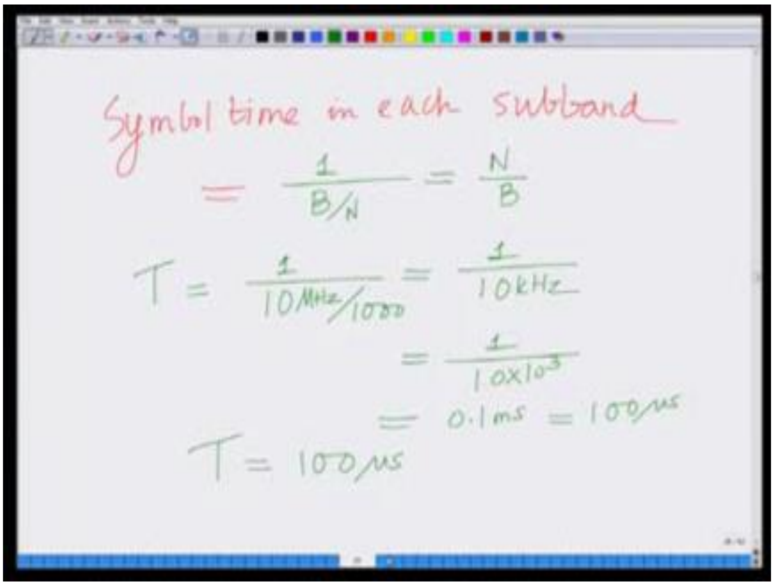

Now, therefore symbol time in each sub band is equal to the symbol time is

$$= \frac{1}{\frac{B}{N}} = \frac{N}{B} = \frac{1000}{10\ MHz} = 0.1\text{ms} = 100\ \mu\text{s}$$

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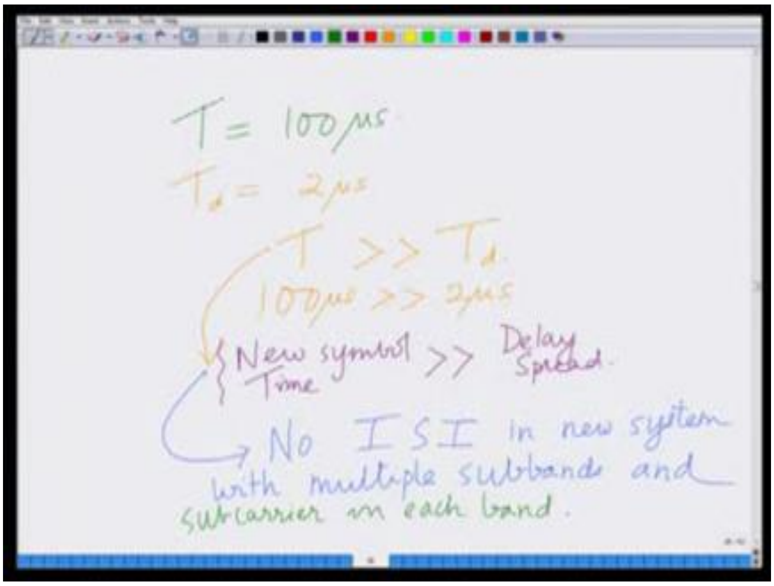

So, now let us they look at this new symbol time which is 100 micro second and compare this, now again with the delay spread which is 2 micro second and now you can see that t is much greater than the delay spread, $T \gg T_d$ that is we have 100 micro seconds is much greater than 2 micro second that is new symbol time, the new symbol time is much greater than and therefore, now what we are seeing is basically the new symbol time is $\frac{1}{\frac{B}{N}}$, that is 1 over the band width of each sub carrier and the band width of each sub carrier is 10 kilohertz.

So, the new symbol times is 1 over 10 kilohertz, which is 0.1 millisecond or 100 micro seconds and the delay spread is 2 micro second. So, the new symbol time which is 100 micro second is significantly greater than the delay spread therefore, there is no inter symbol interference in this system where you are using multiple sub bands and multiple `sub carriers. Therefore, the usage of these multiple sub bands and sub carriers therefore, this means there is no ISI in the new system with multiple sub bands and sub carrier in each band.

So, such a system with multiple sub bands at a sub carrier in each band, so what are we do we are taking band width B dividing into N sub bands in each sub bands there is a sub carrier, so there are n sub carrier such a system with multiple sub bands and multiple sub carriers is termed as a multi carrier system.

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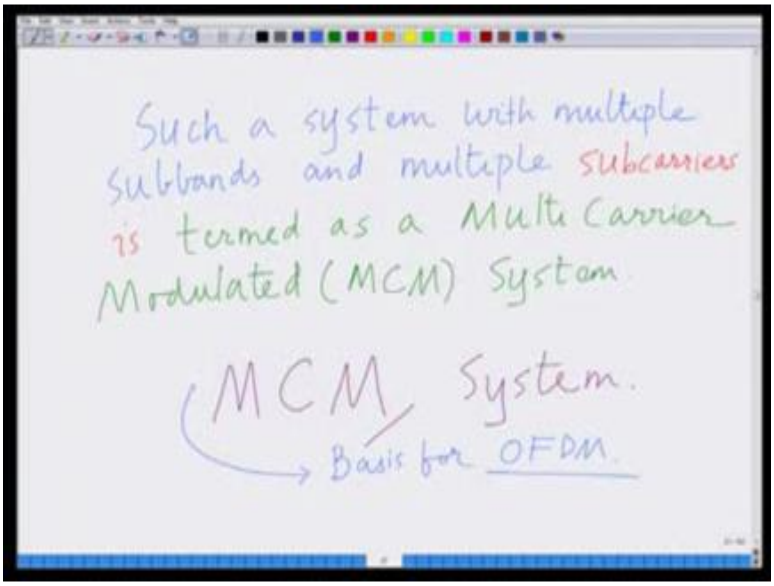

So, such a system with multiple sub bands and multiple sub carries is termed as a Multi Carrier Modulated system. So, this is known as an MCM system which is basically a precursor for OFDM. So, what we see here is that we have a multiple sub carriers, we have multiple sub bands and in each sub band we have a sub carrier therefore, we have multiple sub carriers and we are modulating this multiple sub carriers such a system is known as a multi carrier or multiple carrier modulated system, that is an MCM system and this is the basis for OFDM, this is the precursor or basis for OFDM.

This is not exactly OFDM, this is a basis for OFDM; so what is OFDM? OFDM is basically a multi carrier modulated system that is where we have multiple sub bands and multiple sub carriers, each sub carrier representing a small sub band and since the band width of each sub band is small therefore, the symbol time is large. Once a symbol time is large the symbol time is larger than the delay spread therefore, there is no inter symbol interference or negligible inter symbol interference in each sub band and this enables transmission, this enables smooth transmission and smooth reception in a broad band wireless communication system.

So, that is the principle behind MCM which forms a basis of OFDM that is Orthogonal Frequency Division Multiplexing. And we are going to explore this idea in greater detail in the subsequent modules.

Thank you very much.