Welcome!

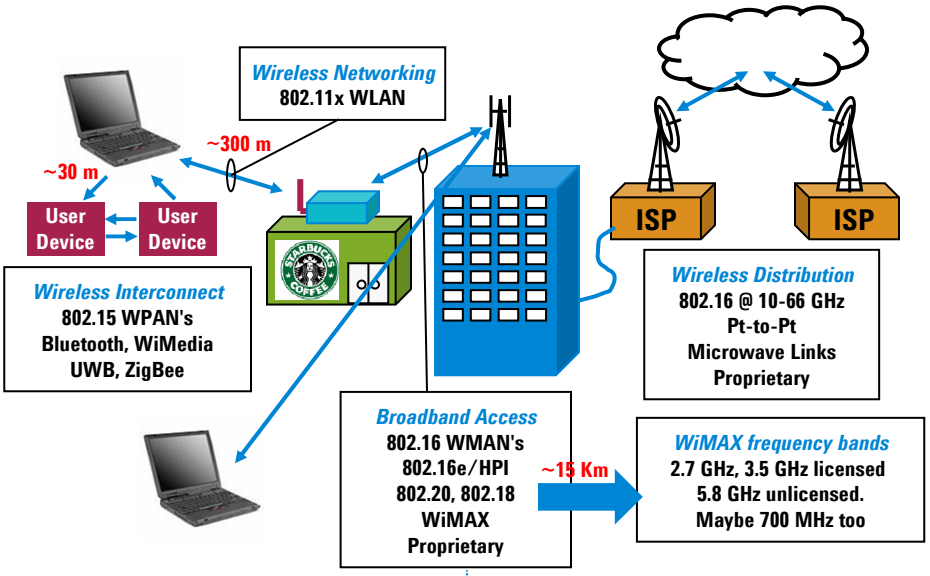
OFDM in Wireless Networking

Agilent Technologies

Topics

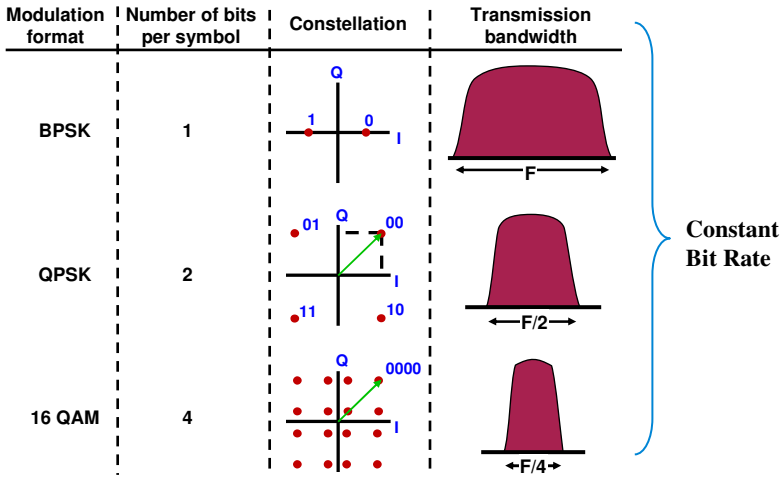
- Introduction
- OFDM Basics
- Wireless LAN (802.11a) OFDM Modulation
- WiMAX (802.16d) OFDM Modulation
- WiMAX (802.16e) OFDMA Modulation
- Conclusion

IEEE 802.xx – A family of Wireless Standards



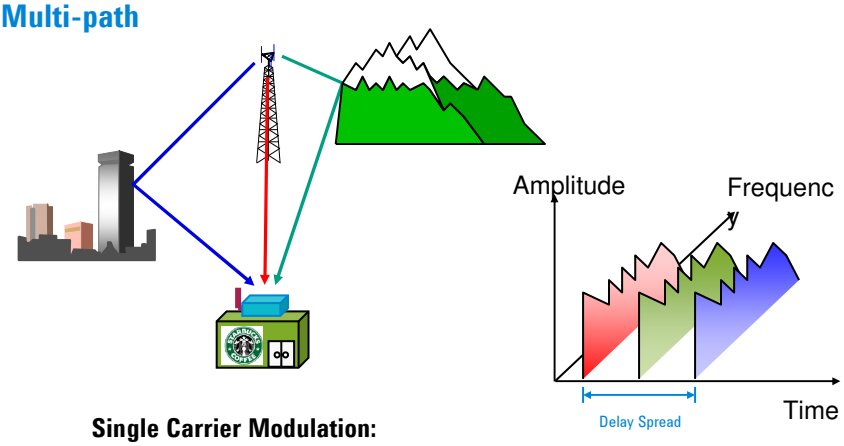
Single Carrier Digital Modulation Characteristics

Transmission Bandwidth is Proportional to Symbol Rate



Motivation for OFDM

Multi-path



Single Carrier Modulation:

As symbol rate is increased to accommodate higher data rates, the symbol interval becomes shorter than the delay spread, creating inter-symbol interference (ISI).

Motivation for OFDM

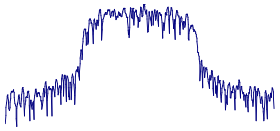
- Orthogonal Frequency Division Multiplexing
- Multi-carrier signaling format enables high data rates using low symbol rates
  - Each carrier = low symbol rate
  - Composite signal = high data rate
- Tightly spaced orthogonal carriers are required for spectral efficiency
- Less suceptible to:
  - Multi-path
  - Fast Fading
  - Single frequency interference
- Concept is NOT new
  - Used in Digital Audio, Digital Video Broadcasting, ADSL, LMDS

Motivation for OFDM

Given: Date rate = 54 Mbps
Mod format = 64QAM
Filter α = .3

✓**Single carrier modulation (SCM) occupied bandwidth:**

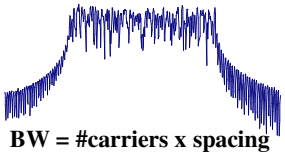
(54 Mbps/6) x 1.3 = 11.7 MHz



BW = Symbol Rate *(1+α)

✓**802.11a/g OFDM occupied bandwidth:**

312.5 kHz x 52 carriers = 16.25 MHz*



BW = #carriers x spacing

OFDM = Reliable, reasonably spectrum efficient, high rate data transmission in multipath environments

Advantages of OFDM

- **Increased efficiency because carrier spacing is reduced (orthogonal carriers overlap)**
- **Equalization simplified, or eliminated**
- **More resistant to fading**
- **Data transfer rate can be scaled to conditions**
- **Single Frequency Networks are possible (broadcast application)**
- **Now possible because of advances in signal processing horsepower**

Disadvantages of OFDM

- Higher Peak-to-average
- More sensitive to phase noise, timing and frequency offsets
- Greater complexity
- More expensive transmitters and receivers
- Efficiency gains reduced by requirement for guard interval

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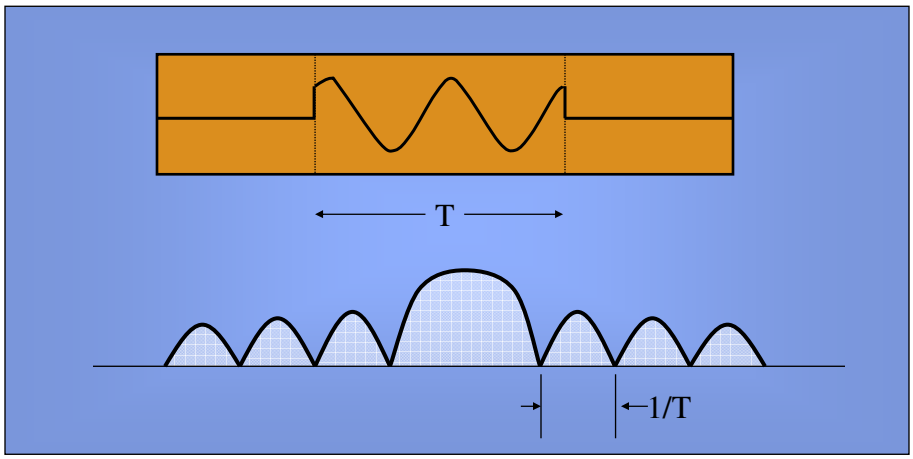
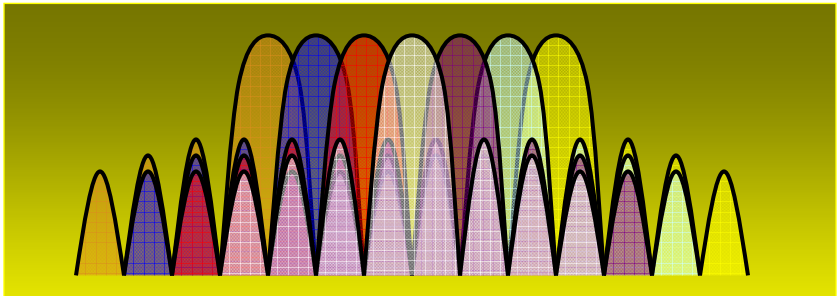
Signal's Spectrum has a Sin(x)/x Shape



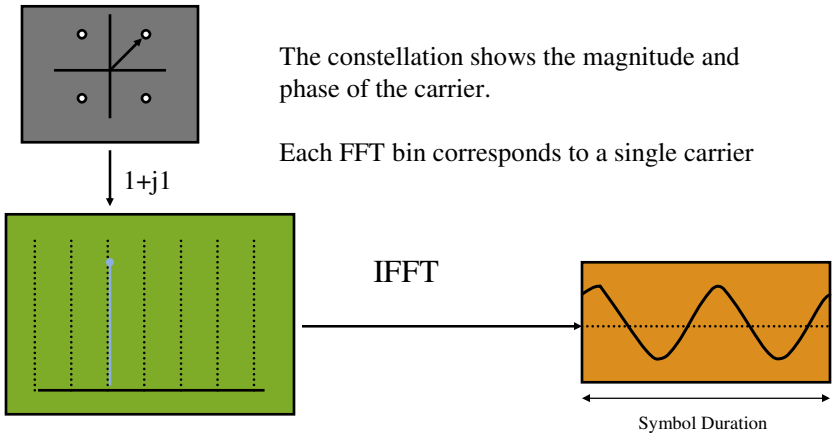
Orthogonal Frequency Division Multiplexing



- Closely spaced carriers overlap
- Nulls in each carrier's spectrum land at the center of all other carriers for Zero Inter-Carrier Interference

IFFT Used to Create Signal

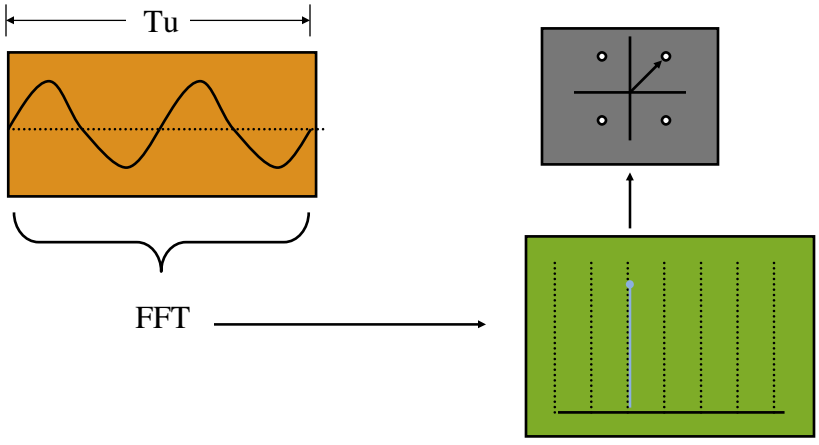
One Carrier Example



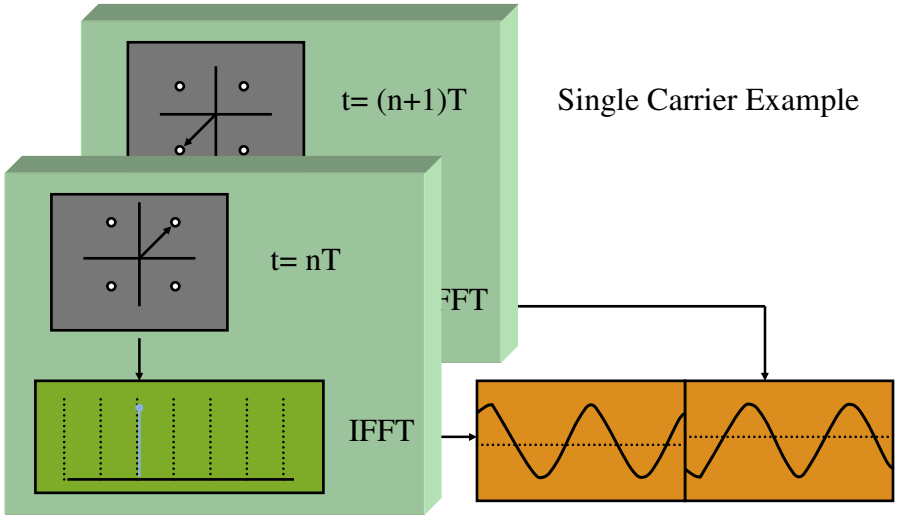
The constellation shows the magnitude and phase of the carrier.

Each FFT bin corresponds to a single carrier

Receiving an OFDM Signal

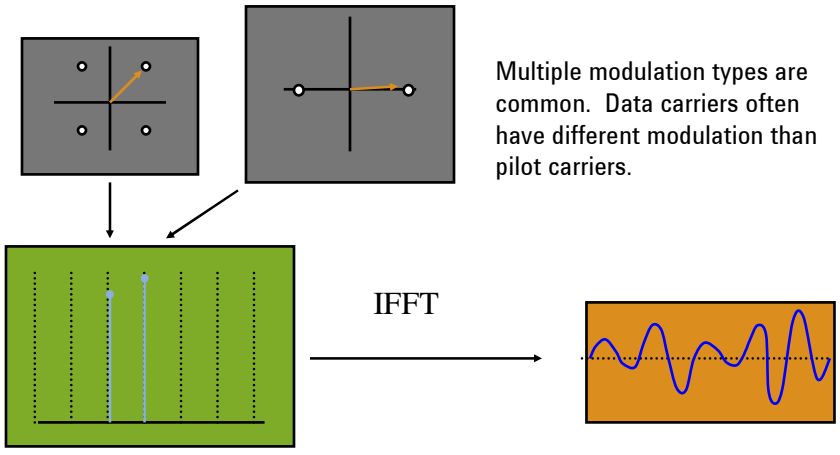


One IFFT per Symbol Period



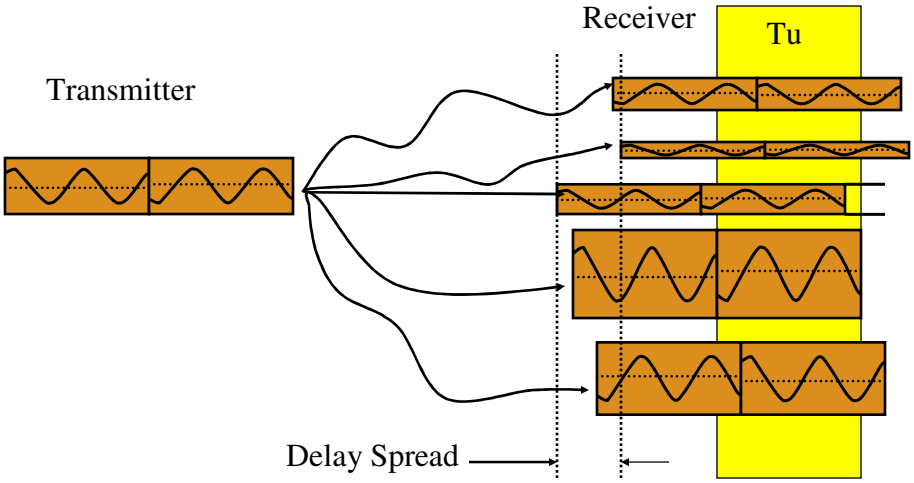
Single Carrier Example

IFFT Used to Create TX Signal
Multiple Carrier example

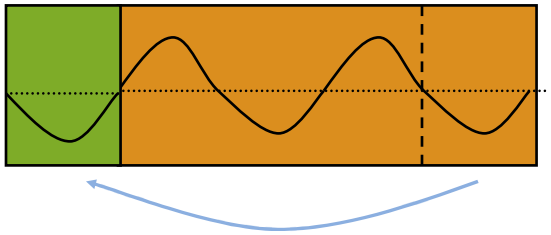


Multiple modulation types are common. Data carriers often have different modulation than pilot carriers.

Dealing With Multipath

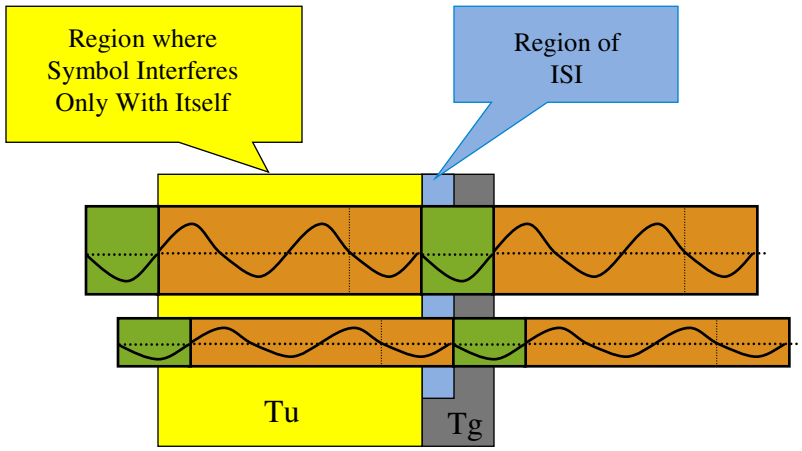


A *Guard Interval* is inserted before Transmission

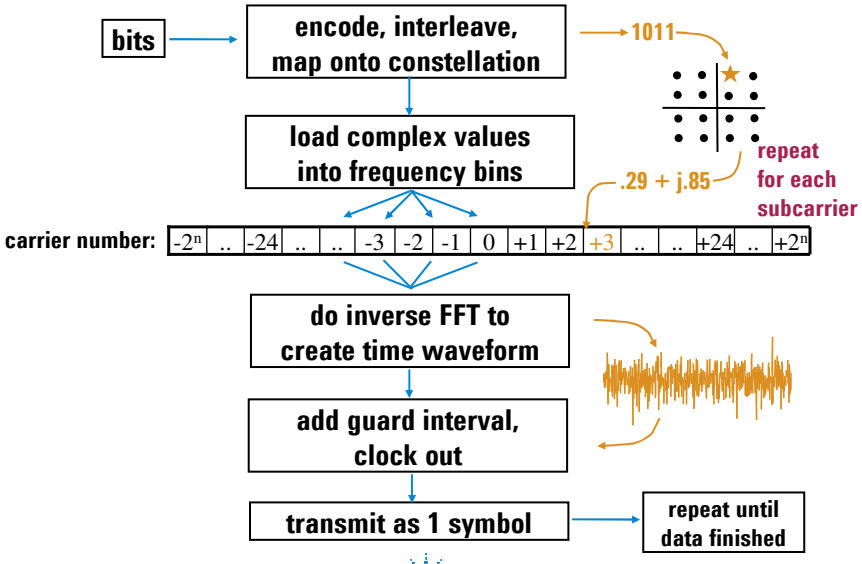


The guard interval is often referred to as a "cyclic extension" .

Dealing With Multipath
Two Paths/Transmitters

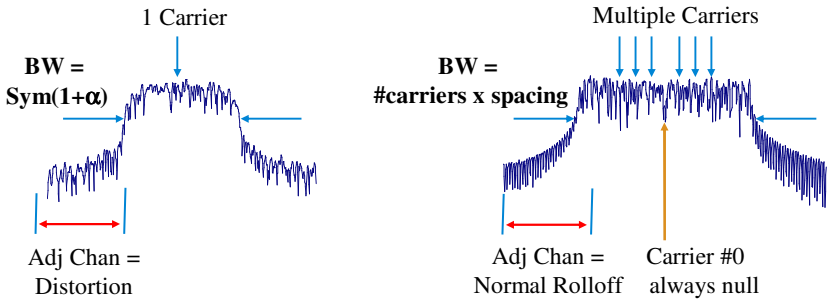


Generating OFDM



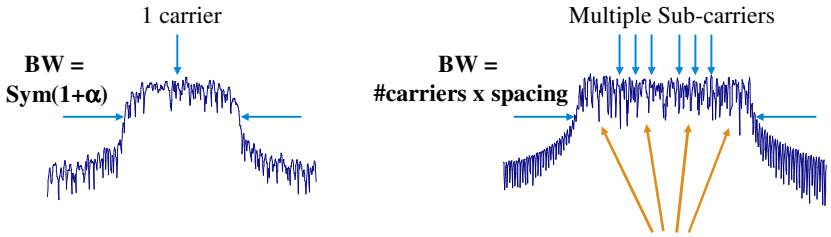
OFDM vs. Single Carrier Modulation

Frequency Domain View



OFDM vs. Single Carrier Modulation

Frequency Domain View



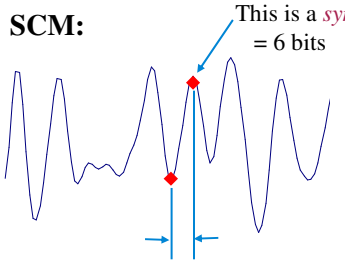
Pilot Carriers

- Typically BPSK
- same amplitude, phase
- used as reference for vector demod.

OFDM vs. Single Carrier Modulation

Time Domain View

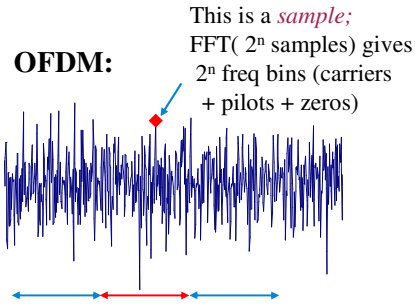
SCM:



1 Sym interval = .083 usec

1 symbol = one point in time
1 point in time = 1 symbol

OFDM:



1 Sym = $1/\Delta F + T_{guard\ int}$
4.0 usec (WLAN)
100.8 us (802.16e)

1 symbol = 1 point in frequency *and* time
1 point in time = ~meaningless

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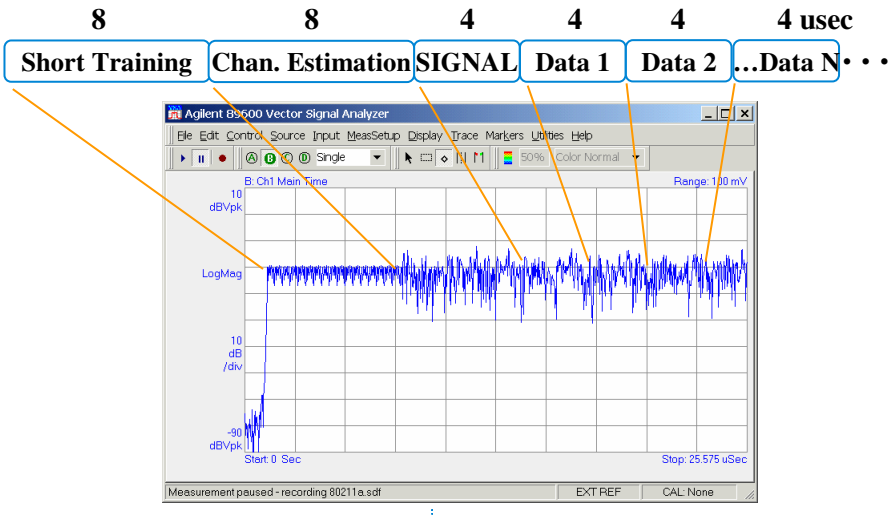
802.11a/g and HIPERLAN type 2

- Almost Identical Physical Layer
- Burst OFDM Modulation
  - 48 Data Carriers: BPSK, QPSK, 16QAM, 64QAM
  - 4 Pilots: BPSK
- Compared to 802.11b:
  - 5-6 GHz Frequency Bands
  - 54 MBits/Sec in the same bandwidth as B's 11 MBit/sec
  - Much Higher Peak-to-Average Power Ratio
  - More Sensitive to Phase Noise

Structure of IEEE802.11a OFDM Frame (= Burst)



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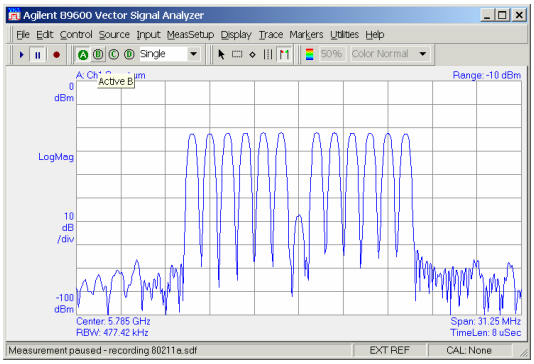
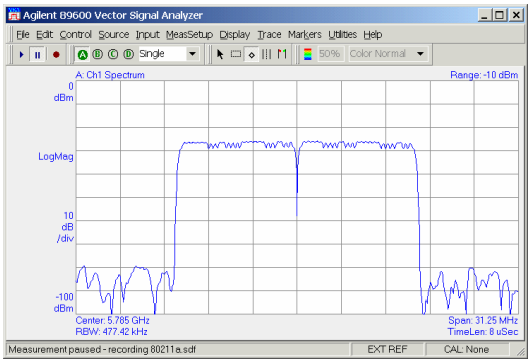


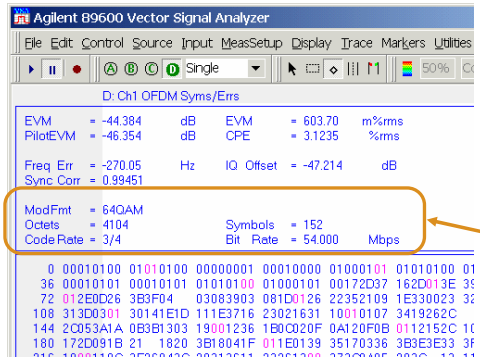
Short Training Seq.
- **8 uSec length**
- **Every 4th carrier, equal amplitude/phase**
- **Signal detect, AGC, timing synchronization, coarse freq. estimation.**

Structure of IEEE802.11a OFDM Frame (= Burst)



Channel Estimation
- **8 uSec length**
- **Every carrier, equal amplitude and phase.**
- **Channel equalization, fine freq. estimation.**

Structure of IEEE802.11a OFDM Frame (= Burst)



SIGNAL Symbol

- **4 uSec length**
- **Always BPSK.**
- **Describes this frame's rate, length.**

These parameters are read from signal under test. (IEEE802.11a only)

Structure of IEEE802.11a OFDM Frame (= Burst)

Data Rate	Mod. Format	Coding Rate	Bits per Symbol
6 Mbits/sec	BPSK	1/2	24
9	BPSK	3/4	36
12	QPSK	1/2	48
18	QPSK	3/4	72
24	16QAM	1/2	96
36	16QAM	3/4	144
48	64QAM	2/3	192
54	64QAM	3/4	216

Also: 54-108 – Atheros chipset"Turbo Mode"

Data Symbols

- **1 symbol =**
  - **4 uSec length**
  - **1 FFT**
  - **52 carriers (48 + 4)**
  - **52 constellation dots**
- **Format varies**
- **Coding varies**
- **Max 4096 bytes per frame.**
- ***MAC layer starts here.***

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- **WiMAX (802.16d) OFDM Modulation**
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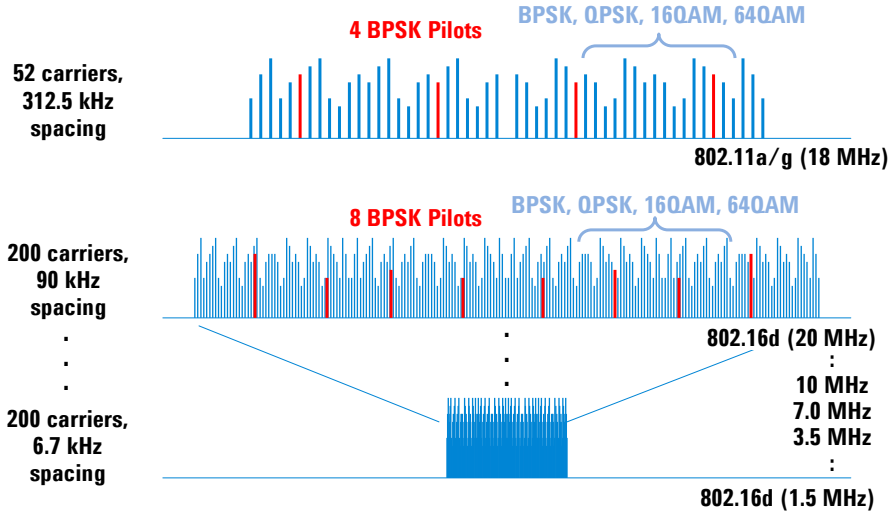
Contrasting OFDMs

802.11a vs. 802.16d WiMAX



Data Rates and Bandwidths—Comparison

Megabits/Sec

802.16-2004 OFDM WiMAX

Final standard added even more BW's than shown here.

Modulation:	QPSK	QPSK	16QAM	16QAM	64QAM	64QAM
Code Rate:	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz	1.04	2.18	2.91	4.36	5.94	6.55
3.5 MHz	2.08	4.37	5.82	8.73	11.88	13.09
7.0 MHz	4.15	8.73	11.64	17.45	23.75	26.18
10.0 MHz	8.31	12.47	16.63	24.94	33.25	37.40
20.0 MHz	16.62	24.94	33.25	49.87	66.49	74.81

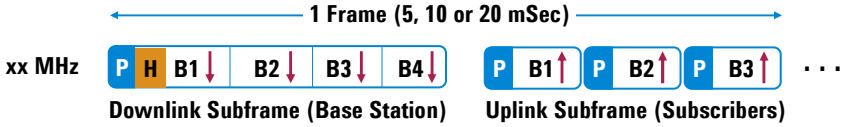
802.11 OFDM WLAN

Modulation:	BPSK	BPSK	QPSK	QPSK	16QAM	16QAM	64QAM	64QAM
Code Rate:	1/2	3/4	1/2	3/4	1/2	3/4	2/3	3/4
18 MHz	6	9	12	18	24	36	48	54

802.16d Concepts

TDD vs FDD vs H-FDD

Time Division Duplexing



PREAMBLE: Long Sync + Channel Estimation Symbols
4 formats: std. DL, AAS DL, std. UL, sub-chan. UL
QPSK Modulation

HEADER: Rate, Length for B1-4; chksum

DL Burst #1: DL, UL "Maps" for B1 thru Bn.

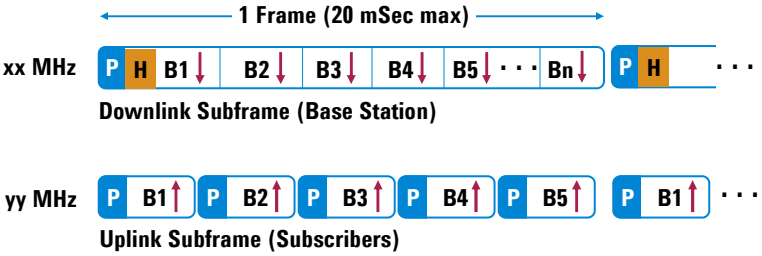
DL BURSTS: Single mod. format, variable length, multiple destinations

UL BURSTS: Single mod. format, variable length, single

802.16 Concepts

TDD vs FDD vs H-FDD

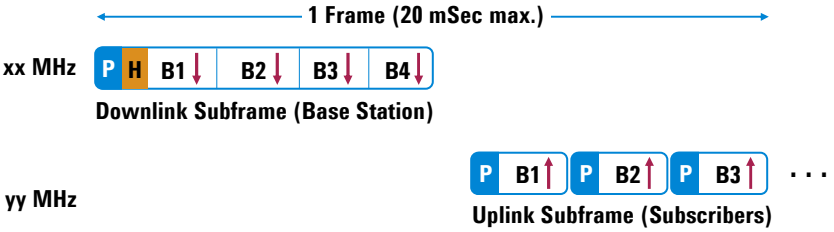
Frequency Division Duplexing



802.16 Concepts

TDD vs FDD vs H-FDD

Half-Duplex FDD



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- **WiMAX (802.16e) OFDMA Modulation**
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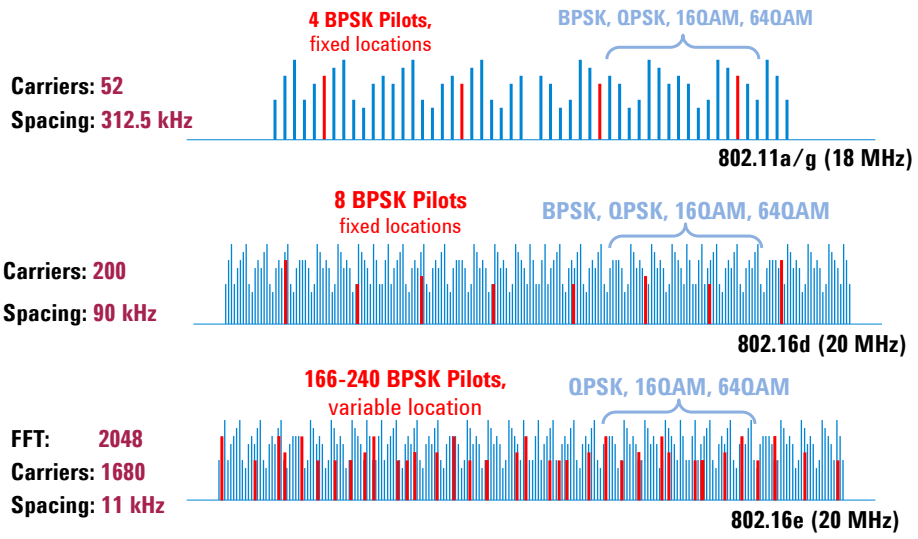
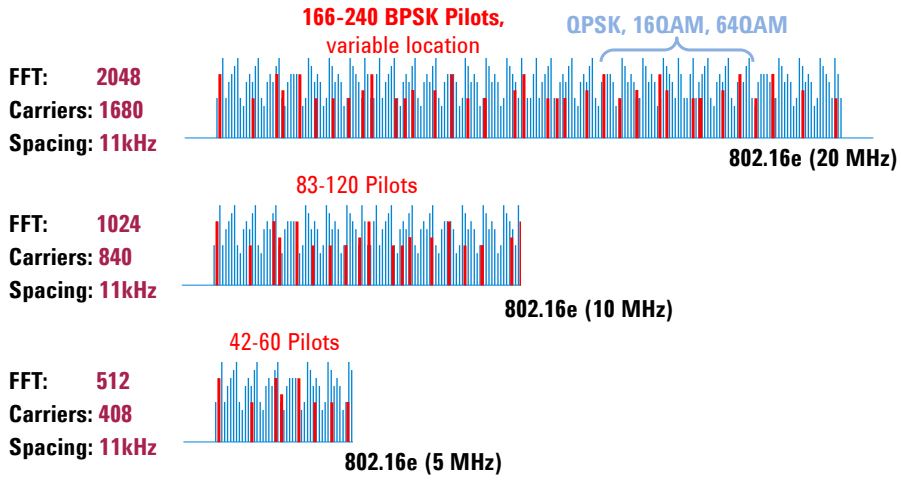
Contrasting OFDMs – *WLAN and WiMAX*



Contrasting OFDMs--*802.16e OFDMA "WiMAX mobile"*

802.16e: Freq range: 2- 6 GHz Data rate: ≤ 70Mbps Mobile/Fixed: Mobile (60kph)



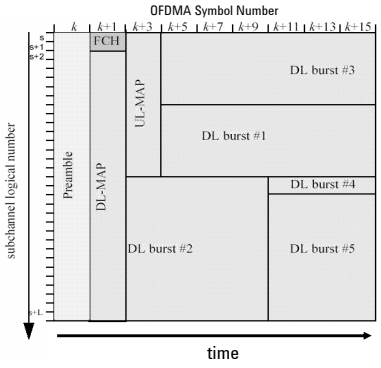
802.16e (1.25 MHz) – Proposed but not practical

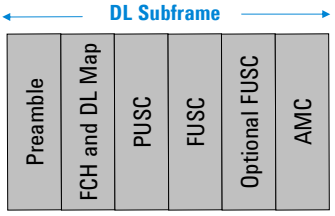
802.16 Concepts

New OFDMA terminology

There are many new terms being introduced to describe the new OFDMA PHY layer. Here are some of the key new terms and how they are related to each other.

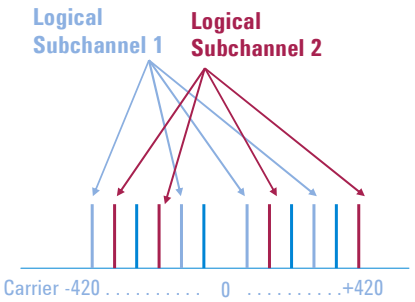
- Logical sub channel – randomly distributed group of carriers
- Slots – smallest data unit (symbol x logical subchannel)
- Data Burst – block of adjacent slots
- Permutation Zone – group of adjacent slots, carriers, pilots, sub channels, controlled by same PR permutation formula. (Beam forming, sector assignment, reduce base station interference)
- PUSC / FUSC / AMC (some of the basic zones)





(A subframe can contain multiple zone types)

802.16 Concepts
Sub-channelization



•The carriers are organized into "logical sub-channels". The carriers are usually NOT adjacent carriers, they are randomly distributed across the entire bandwidth.

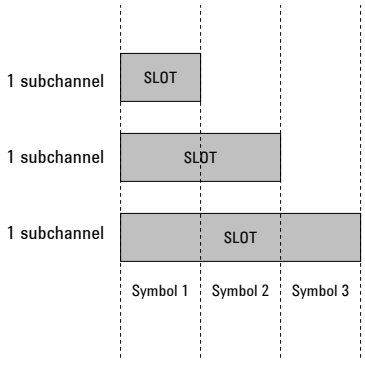
• 34 logical sub-channels,

• 24.7 carriers/sub-channel (10MHz)

• Carrier assignment changes for every symbol (p/o permutation formula)

Permutation formula = pseudo-random sequence determined by preamble index, cell ID and segment number. Provides more reliable link also signaling control

802.16 OFDMA Concepts
Slots



• In OFDMA, the minimum possible data unit is a "Slot"

• A slot has 2 dimensions, one dimension is time, the other is subchannel number

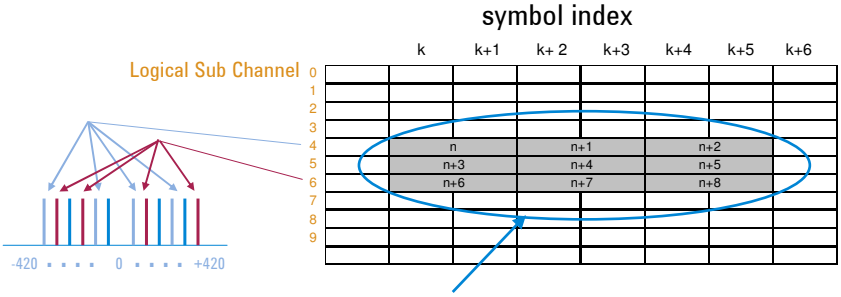
• There are 3 different slot sizes

- •1 Subchannel and 1 OFDMA Symbol
- •1 Subchannel and 2 OFDMA Symbols
- •1 Subchannel and 3 OFDMA Symbols

• Different "Zones" will use different slot sizes

802.16 OFDMA Concepts

Example of a 'data burst' or 'data region' allocated to a user

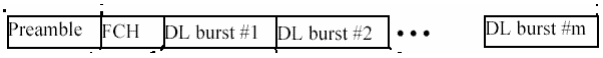


- Slots are combined together to make a data burst (aka region)
- A data burst is a group of contiguous sub channels and symbols
- The base station assigns a data burst/region to a user to use to receive or transmit data.

802.16 OFDMA Concepts

Drawing of 'data region' or 'data bursts'

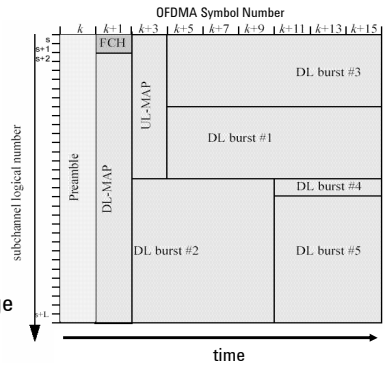
OFDM



- In 802.16-2004 OFDM user data DO NOT overlap in time.

OFDMA

- In OFDMA, data bursts overlap in time
  - Maximizes data flow in complex environment
- Preamble
  - Every 3rd Carrier, BPSK
  - Preamble Index Determines Subcarrier Usage
- Frame Control Header - QPSK Modulated



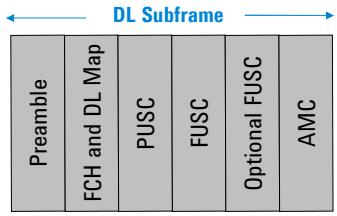
802.16 OFDMA Concepts

Zones

• A Permutation Zone (or simply a Zone) is a number of contiguous OFDMA symbols in the DL or UL that use the same permutation formula. The permutation formula describes various configurations of pilot subcarriers, data subcarriers, subchannels, and slots.

• There are currently at least 7 zones that have been defined

- •PUSC (partial usage of subchannels)
- •FUSC (full usage of subchannels)
- •PUSC with all subchannels
- •Optional FUSC
- •AAS (Adaptive Antenna System)
- •AMC (Adaptive Modulation and Coding ??)
- •Option FUSC with all subchannels



(A subframe can contain multiple zone types)

• Zones are used to help implement basestation functionality such as beamforming, assigning subchannels to different sectors of a single cell, and to define subchannelization that reduces basestation to basestation interference

802.16 OFDMA Concepts

Basic Zone Types – FUSC, PUSC, and AMC

We won't try to understand all the complexity and flexibility in each of the 7 zone types. The following definitions are for a couple basic zone types (FUSC, PUSC, and AMC). The other zone types are similar (although used for special purposes such as beamforming, multicast, etc)

• **FUSC** or "Fully Used Subchannelization" is one of the zone types used in OFDMA. As the name implies, all the subchannels and subcarriers are used.

• **PUSC** or "Partially Used Subchannelization" is also a zone type. In PUSC, only some of the available subcarriers and therefore only some of the possible subchannels are used. This would be commonly used to assign a portion of a full channel to each sector in a cell

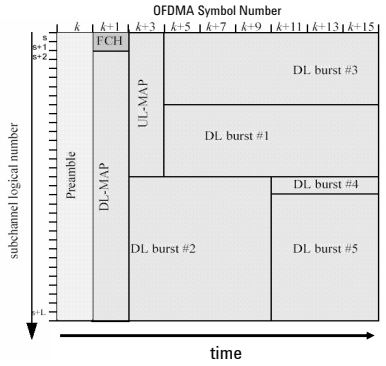
• **AMC** or "Advanced Modulation and Coding" uses subchannels that are made up of adjacent subcarriers. In a fixed or nomadic environment, this can be used to rapidly characterize and adjust modulation and coding for each subchannel. This is useful to continually maximize efficiency (as the link conditions change). The drawback is that the subchannel doesn't benefit from spread spectrum and is vulnerable to frequency selective fading. This is not as useful for full mobility operation.

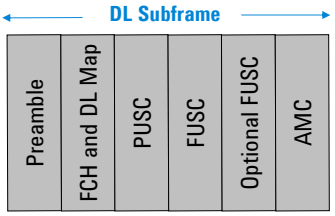
802.16 Concepts

OFDMA terminology Summary

There are many new terms being introduced to describe the new OFDMA PHY layer. Here are some of the key new terms and how they are related to each other.

- Logical sub channel – randomly distributed group of carriers
- Slots – smallest data unit (symbol x logical subchannel)
- Data Burst – block of adjacent slots
- Permutation Zone – group of adjacent slots, carriers, pilots, sub channels, controlled by same PR permutation formula. (Beam forming, sector assignment, reduce base station interference)
- PUSC / FUSC / AMC (some of the basic zones)





(A subframe can contain multiple zone types)

Conclusions

- **OFDM offers many advantages:**
  - **Robust, spectral efficient data transfers**
  - **More resistant to fading**
  - **Equalization simplified, or eliminated**
  - **Data transfer rate can be scaled to conditions**
- **At the expense of:**
  - **Higher Peak-to-average ratio signal statistics**
  - **More sensitivity to phase noise, timing and frequency offsets**
  - **Greater complexity**
  - **More expensive transmitters and receivers**
- **OFDM is commercially viable because of advances in signal processing horsepower**

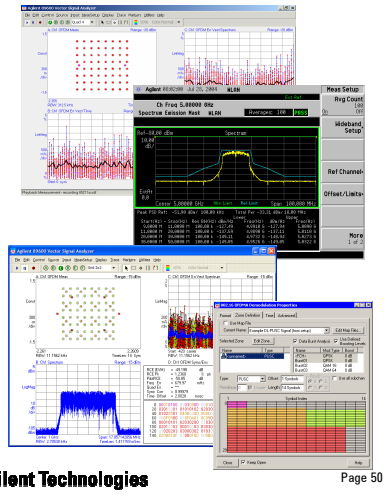
Reference Information

- **References**
  - **RF Testing of Wireless LAN Products, Application Note 1380-1, Agilent Technologies, Inc. ,September 29, 2001, Publication # 5988-3762EN**
  - **IEEE 802.11 Wireless LAN PHY Layer (RF) Operation and Measurement, Application Note 1380-2, Agilent Technologies, Inc., April 1, 2002, Publication # 5988-5411EN**
  - **WiMAX Concepts and RF Measurements, IEEE 802.16-2004 WiMAX PHY layer operation and measurements, January 5, 2005, Publication # 5989-2027EN.**
  - **WiMAX Signal Analysis Parts 1, 2, and 3. July 5, 2005, Publication # 5989-3037EN, 5989-3038EN, and 5989-3039EN.**
- **For More Information:**
  - http://www.agilent.com/find/wlan/
  - http://www.agilent.com/find/wireless
  - IEEE 802.16 Broadband Wireless Access Working Group (download 802.16 standard) http://grouper.ieee.org/groups/802/16/index.html
  - "Peering Into the WiMAX Spec" – excellent overview article from EETimes. http://www.commsdesign.com/showArticle.jhtml?articleID=17500156
  - WiMAX organization – "promoting interoperability standards for broadband access" http://www.wimaxforum.org

OFDM Vector Signal Analysis Solutions

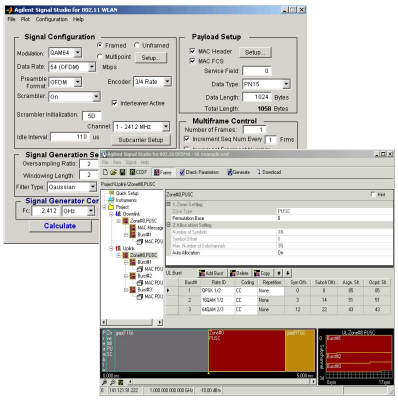
E4440A with 40 MHz or 80MHz BW ADC

- **802.11 a/g**
  - **89601A-B7R (RF, IF, Analog IQ, Digital IQ)**
    - **Modulation Quality**
    - **Advanced Troubleshooting**
  - **PSA Option 217 (RF,IF only)**
    - **Basic EVM, Power, and Time Measurements**
- **802.16d OFDM**
  - **89601A-B7S (RF, IF, Analog IQ, Digital IQ)**
    - **Modulation Quality**
    - **Advanced Troubleshooting**
- **802.16e OFDMA**
  - **89601A-B7Y (RF, IF, Analog IQ, Digital IQ)**
    - **Modulation Quality**
    - **Advanced Troubleshooting**



OFDM Signal Generation Solutions

- 802.11a/g
  - Signal Studio for WLAN (E4438-417)
    - Create Standard Compliant 802.11 a/b/g frames
- 802.16d OFDM
  - Signal Studio for 802.16-2004 (N7613A)
    - Create 256 Carrier OFDM waveforms that comply with the 802.16-2004 standard
- 802.16e OFDM
  - Signal Studio for 802.16 OFDMA (N7615A)
    - Create Mobile WiMAX and WiBro Waveforms that comply with the IEEE WirelessMAN-OFDMA PHY Standards



Thank You!

Agilent Technologies