W-OFDM Submission to IEEE 802.16.3 PHY

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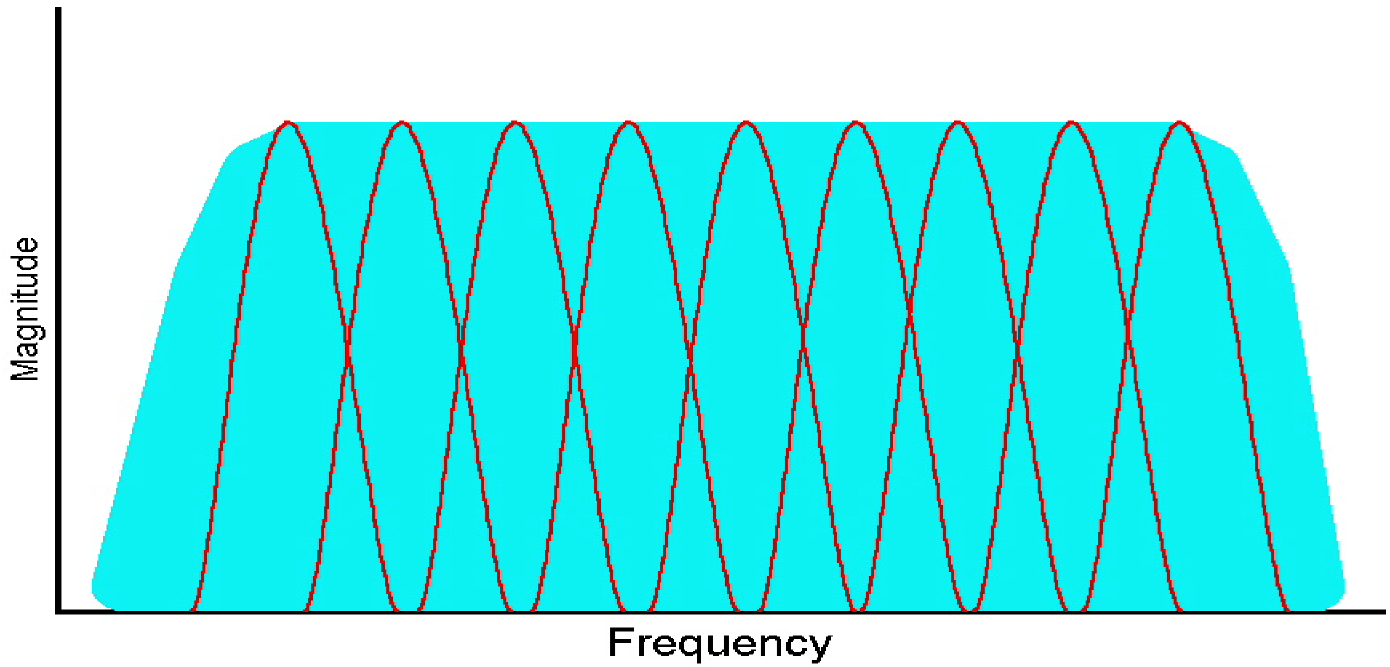
Purpose:
The information in this presentation supplements the submitted proposal, **W-OFDM Submission to IEEE 802.16.3 PHY**.

W-OFDM Submission to IEEE 802.16.3 PHY

by

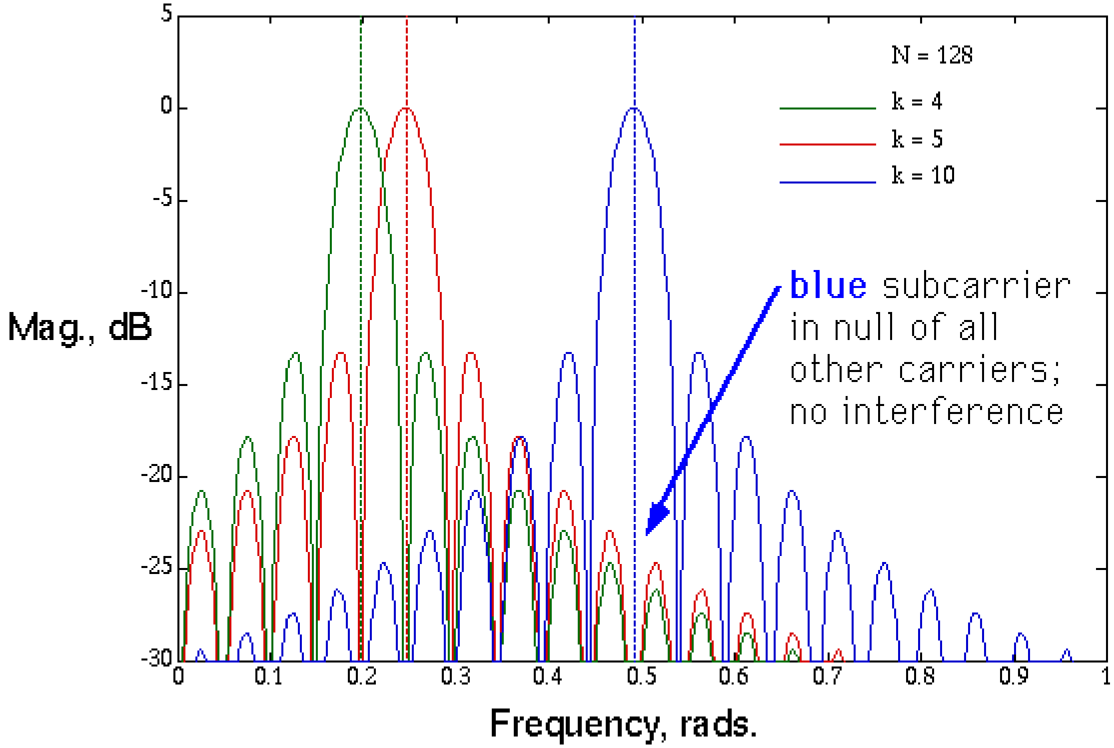
Bob Heise

OFDM
Orthogonal Frequency Division Multiplexing



- **The main idea behind OFDM is the division of the available spectrum into many sub channels (or sub carriers).**

Orthogonality and the DFT



- **The inverse DFT ensures that the spacing and the spectral shape of the sub carriers are such that the spectra of the individual sub carriers is zero at the other sub carriers. That is, the sub channels are orthogonal.**

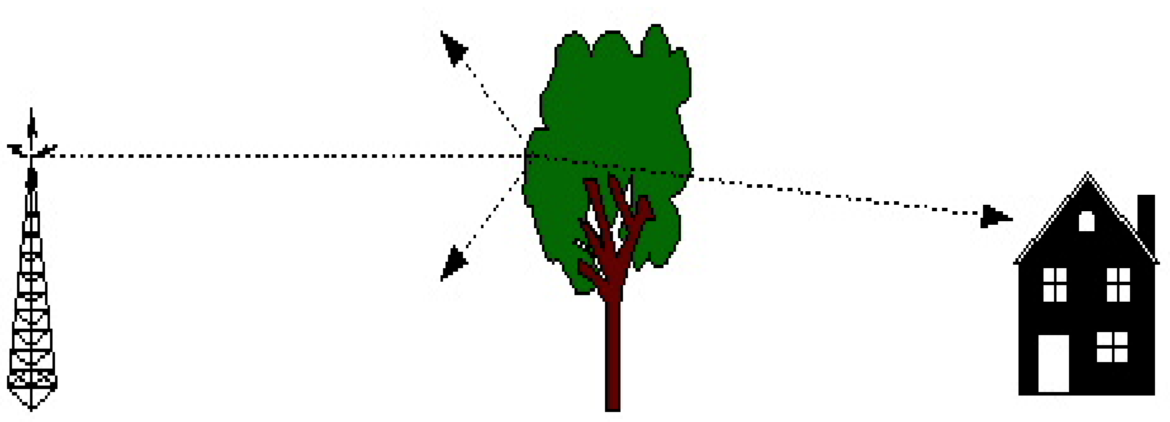
Bandwidth Efficiency

- This allows the sub channels to be overlapped.
- The result is a transmission method that provides very good bandwidth efficiency.
  - Approaches log2(M) bits/s/Hz,
  - where M is the number of points in the “pre-modulation” constellation onto which the data bits are mapped for each sub channel symbol
- This is as good or better than narrowband modulation methods and much better than spread spectrum methods, which have typical bandwidth efficiencies of less than 0.2 bits/s/Hz.

OFDM and Non Line of Sight (NLOS)

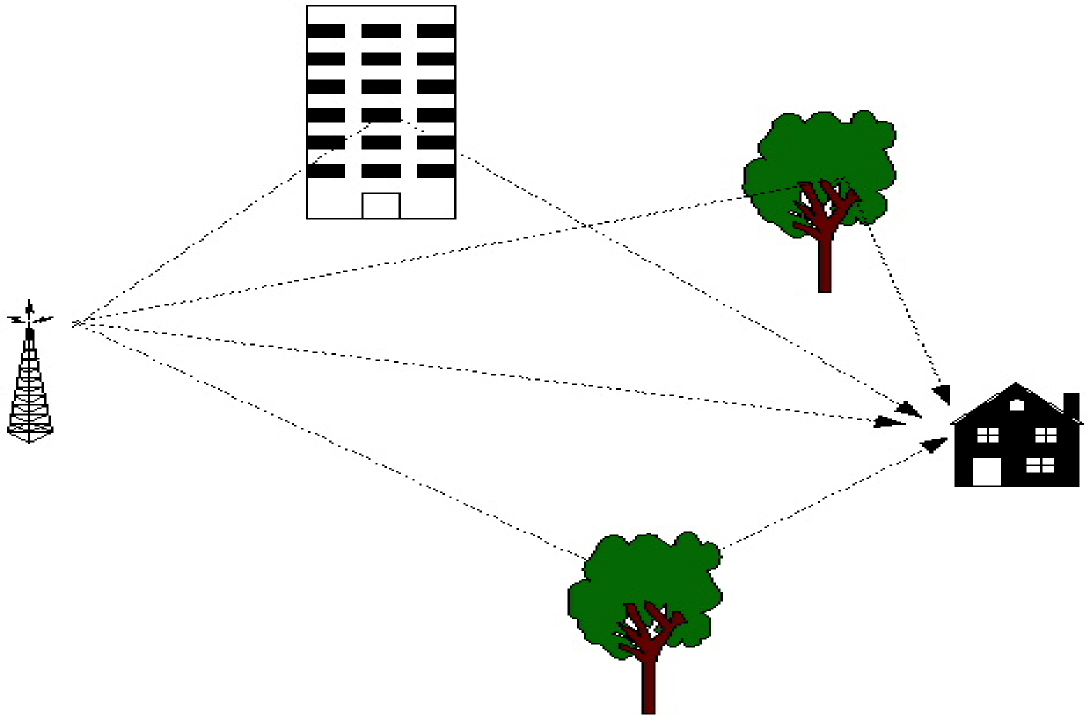
- Non-line-of-sight (NLOS) transmission is when the transmitter and receiver have reflectors and/or absorbers between the two antennae.
- This results in a degradation of the received signal power or “Fading”.
- NLOS results in two distinct types of Fading.
  - Flat Fading
  - Frequency Selective Fading

Flat Fading



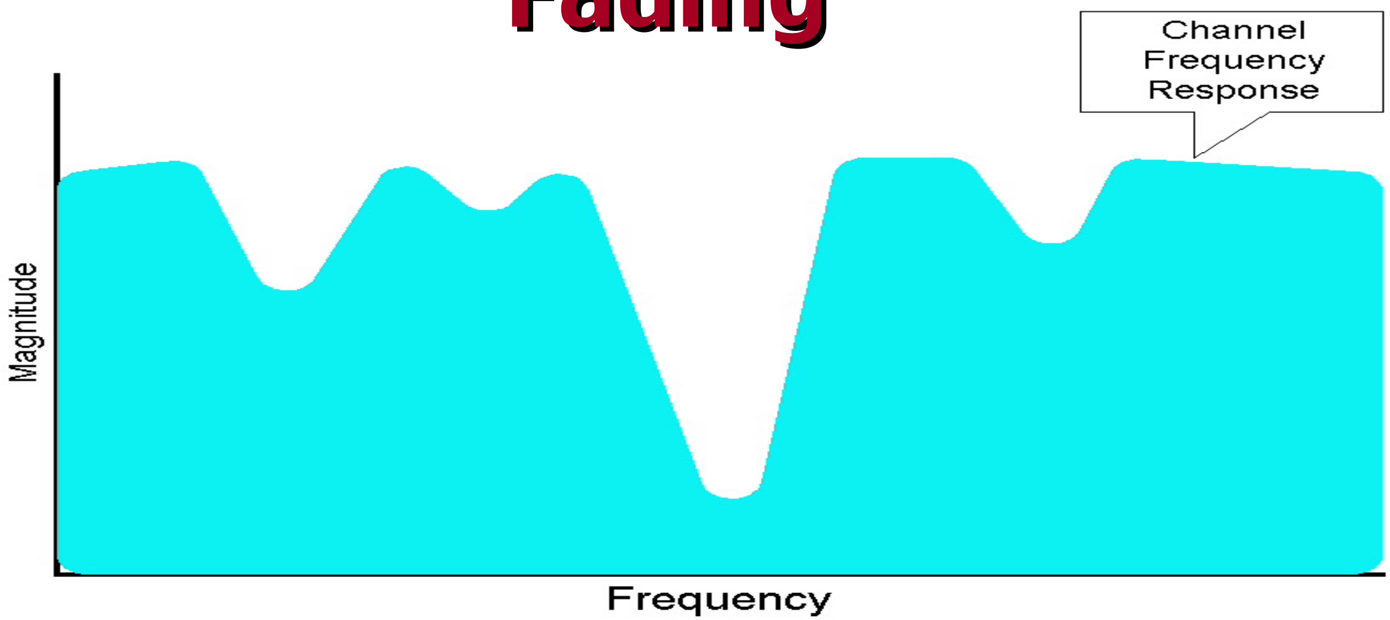
- Flat fading is caused by absorbers between the two antennae and is countered by antenna placement and transmit power level.

Frequency Selective Fading



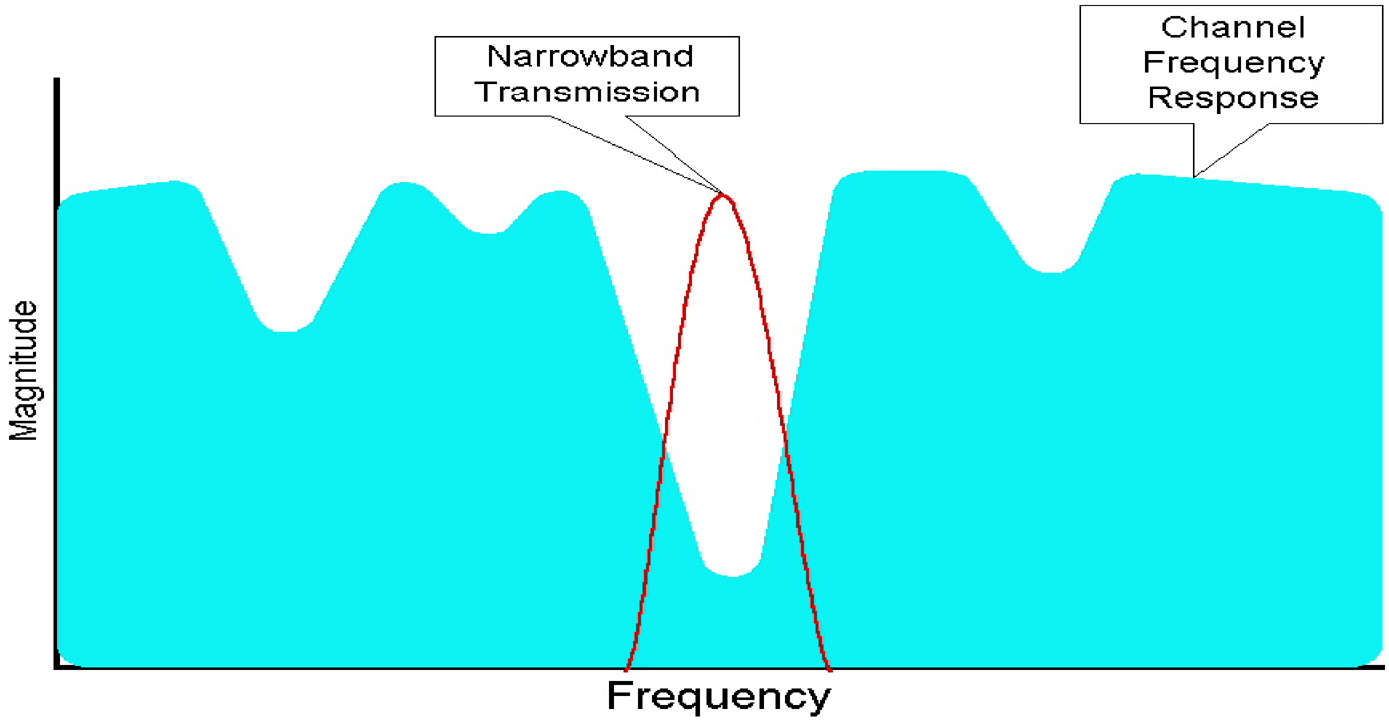
- Frequency selective fading is caused by reflectors between the transmitter and receiver creating multipath effects.

Frequency Selective Fading



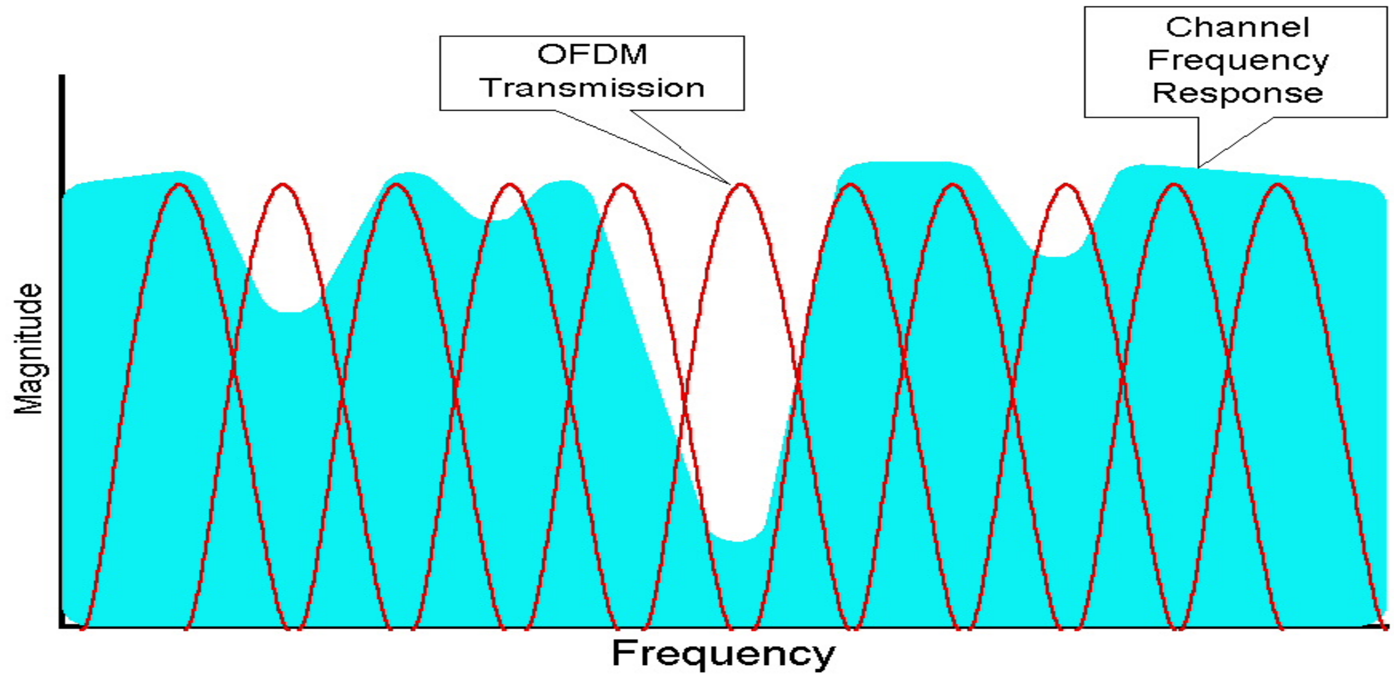
- In radio transmissions, the channel spectral response is not flat. It has dips or fades in the response due to reflections causing cancellation of certain frequencies at the receiver.
- Reflections off near-by objects (e.g. ground, buildings, trees, etc) can lead to multipath signals of similar signal power to the direct signal.
- This can result in deep nulls in the received signal power due to destructive interference

Narrowband in Frequency Fade



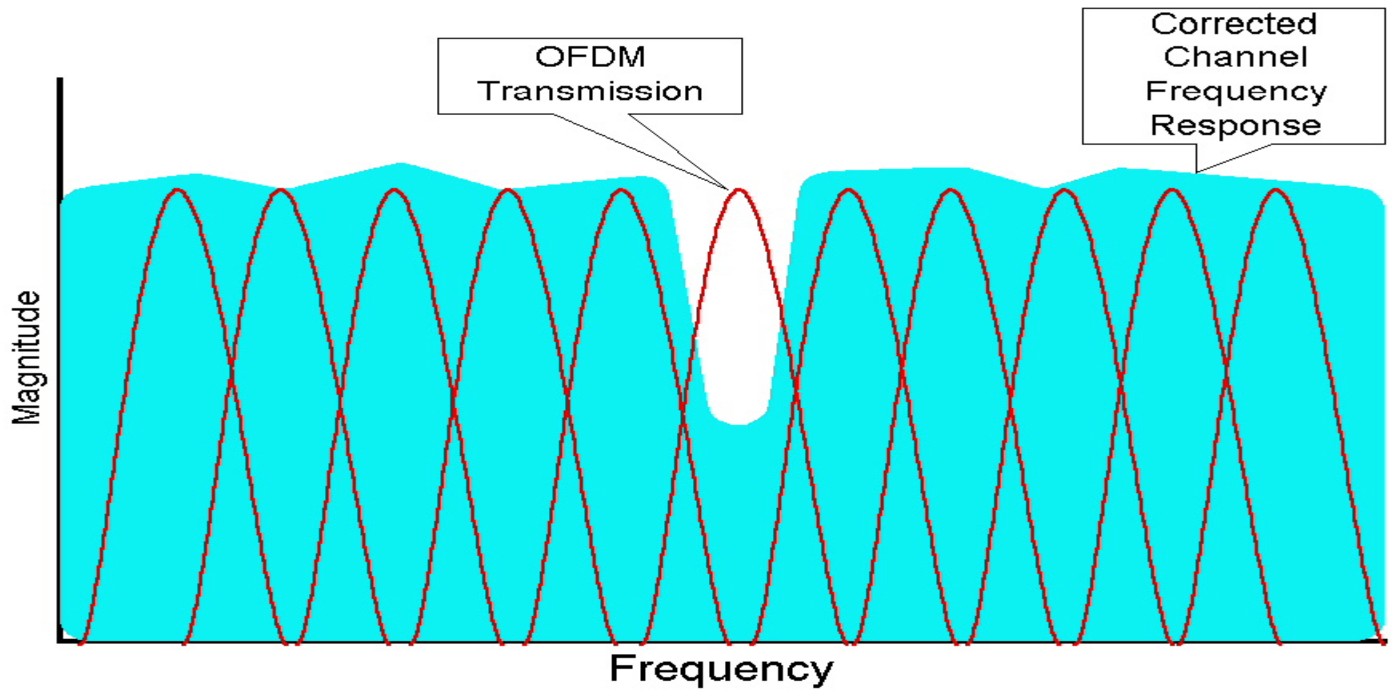
- **For narrow bandwidth transmissions, if the null in the frequency response occurs at the transmission frequency then the entire signal can be lost.**

OFDM in Frequency Fade



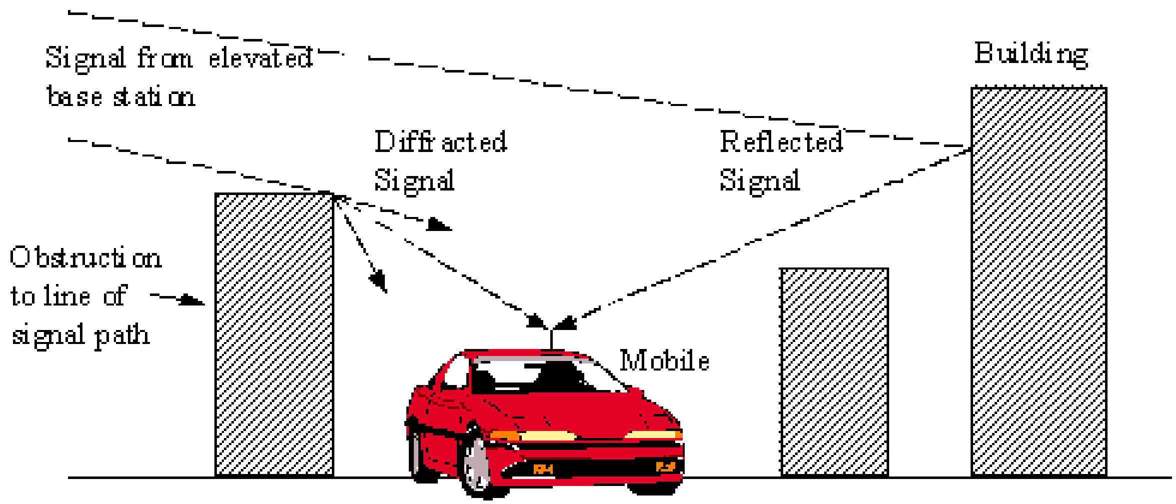
- **OFDM splits the transmission up into many small bandwidth carriers.**
- **The original signal is spread over a wide bandwidth, thus any nulls in the spectrum are unlikely to occur at all of the carrier frequencies.**
- **This will result in only some of the carriers being lost, rather than the entire signal.**

OFDM in Frequency Fade



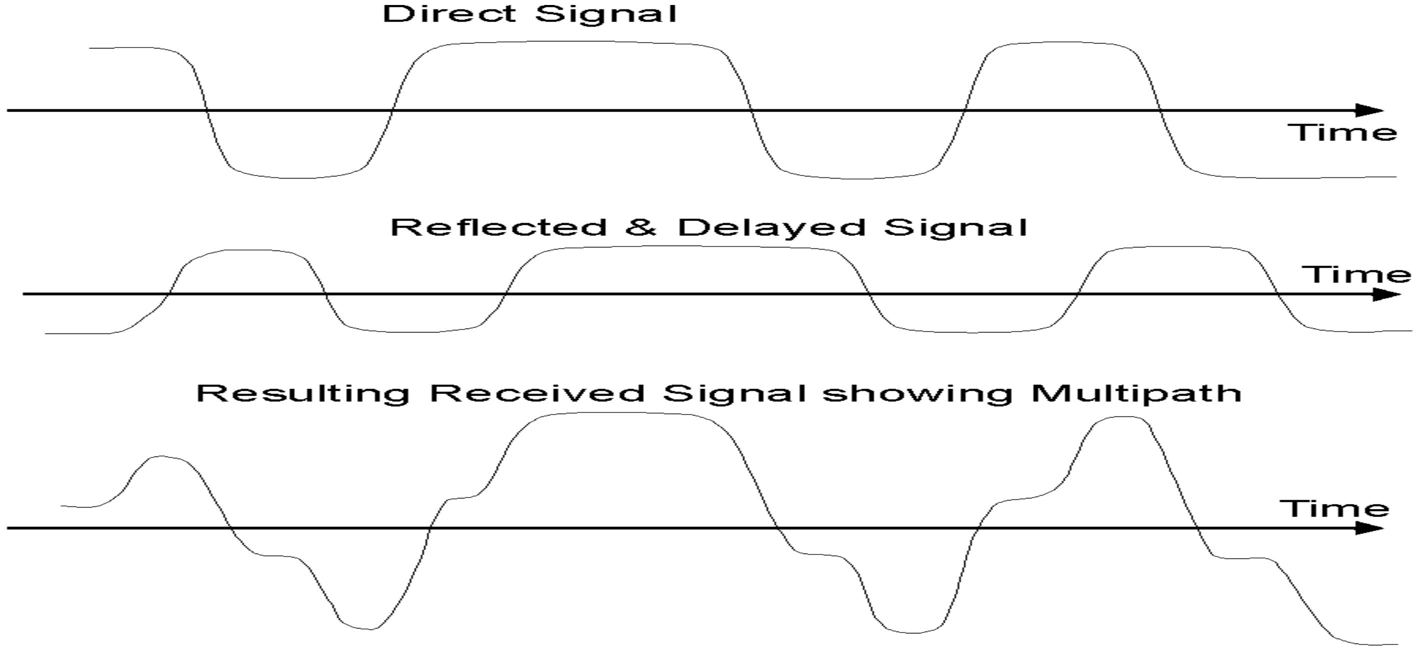
- Channel estimates are also obtained during transmission and used to correct channel distortions in received signals.
- Any carriers that are lost due to uncorrectable nulls can still be recovered using Forward Error Correction.

Other Multipath Concerns



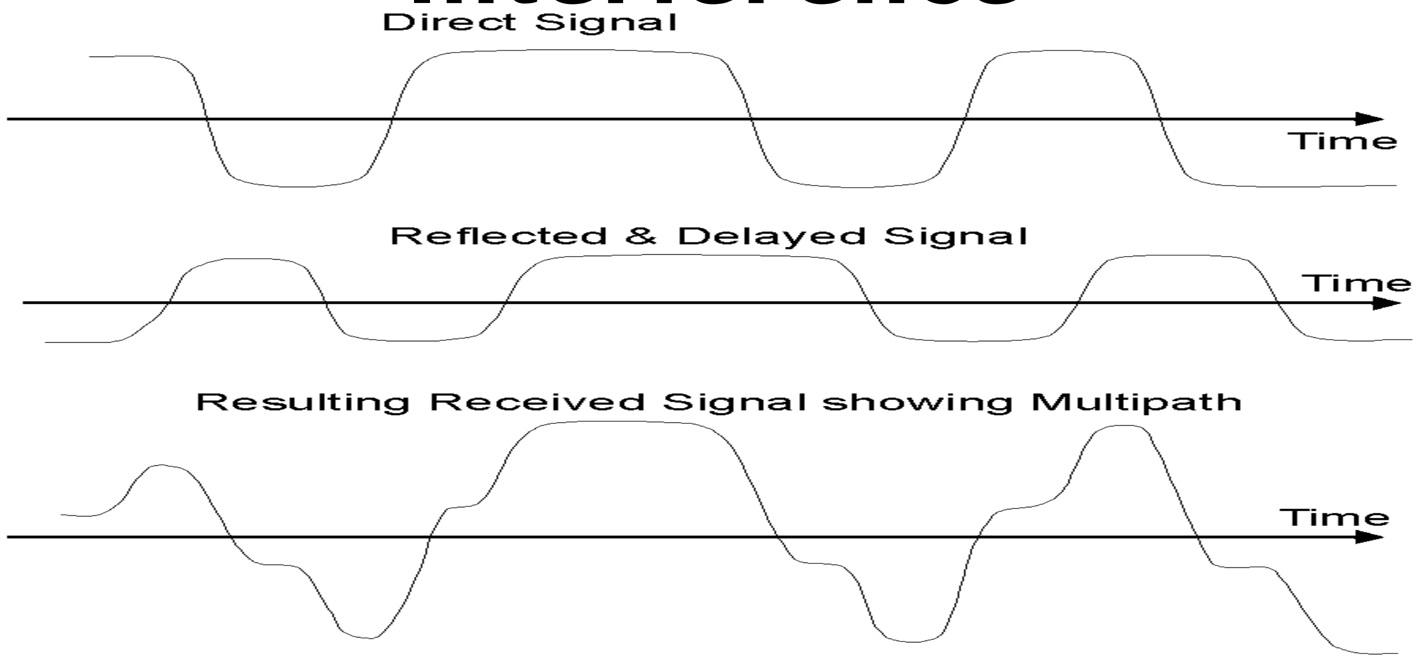
- As well as creating frequency select fading, multipath can also cause inter-symbol interference.

Inter-symbol Interference



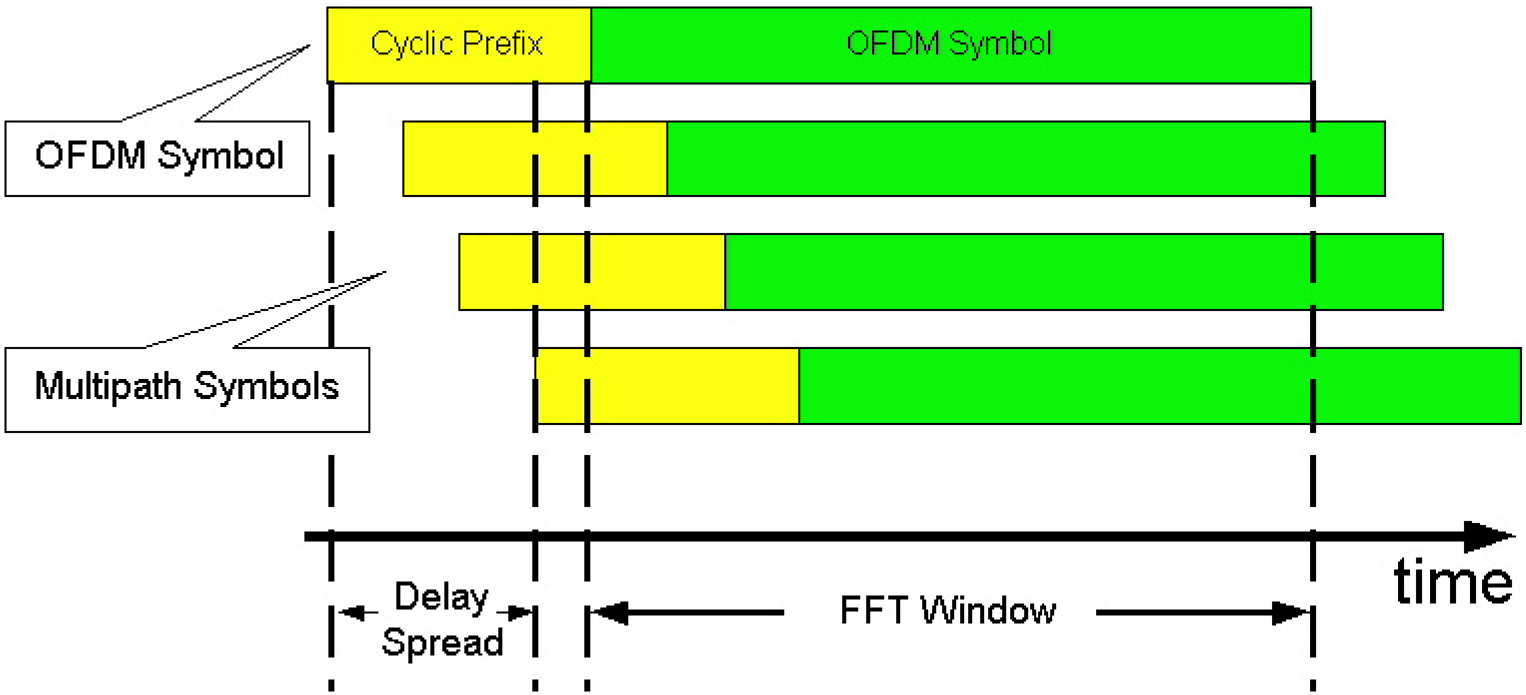
- In a digital system, the delay spread can lead to inter-symbol interference.
- This is due to delayed multipath signals overlapping each other.
- This can cause significant errors in high bit rate systems.

Inter-symbol Interference



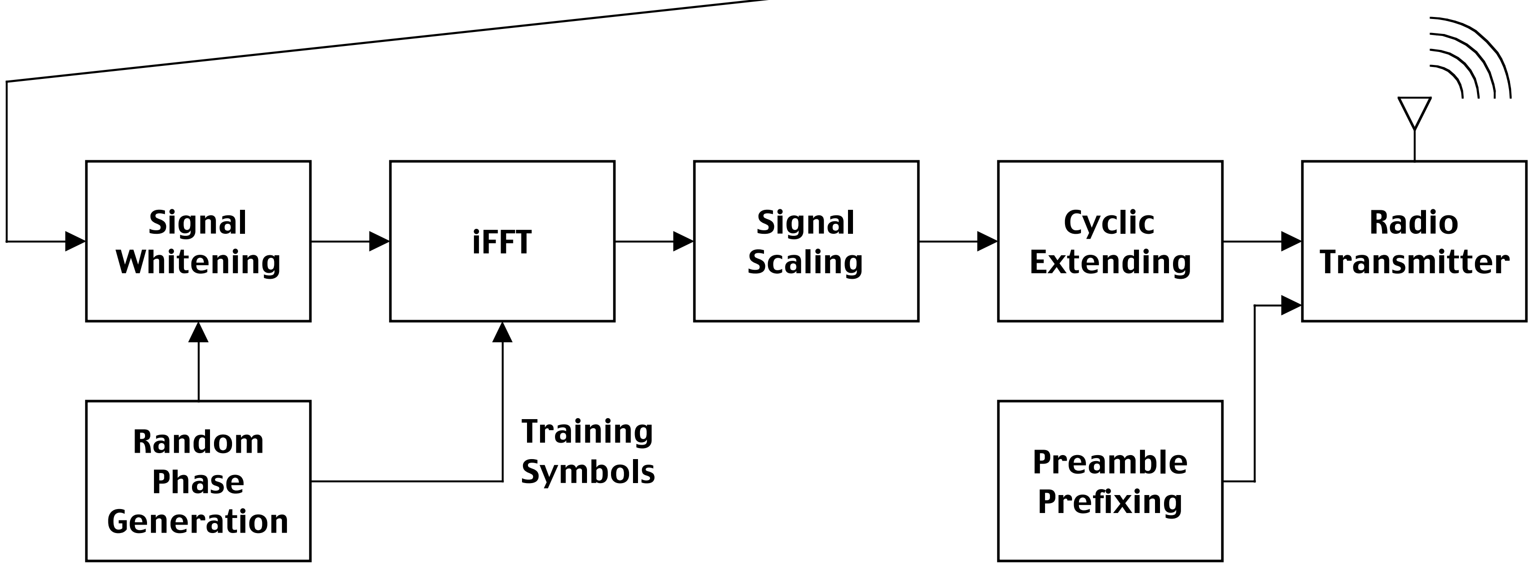
- Inter-symbol interference can be reduced by reducing the data rate.
- OFDM accomplishes this by dividing the data stream into a number of lower rate data streams and then transmitting each one on a separate sub-channel

Inter-symbol Interference



- **Inter-symbol interference is further reduced by incorporating a cyclic extension to each OFDM symbol.**

OFDM Transmitter



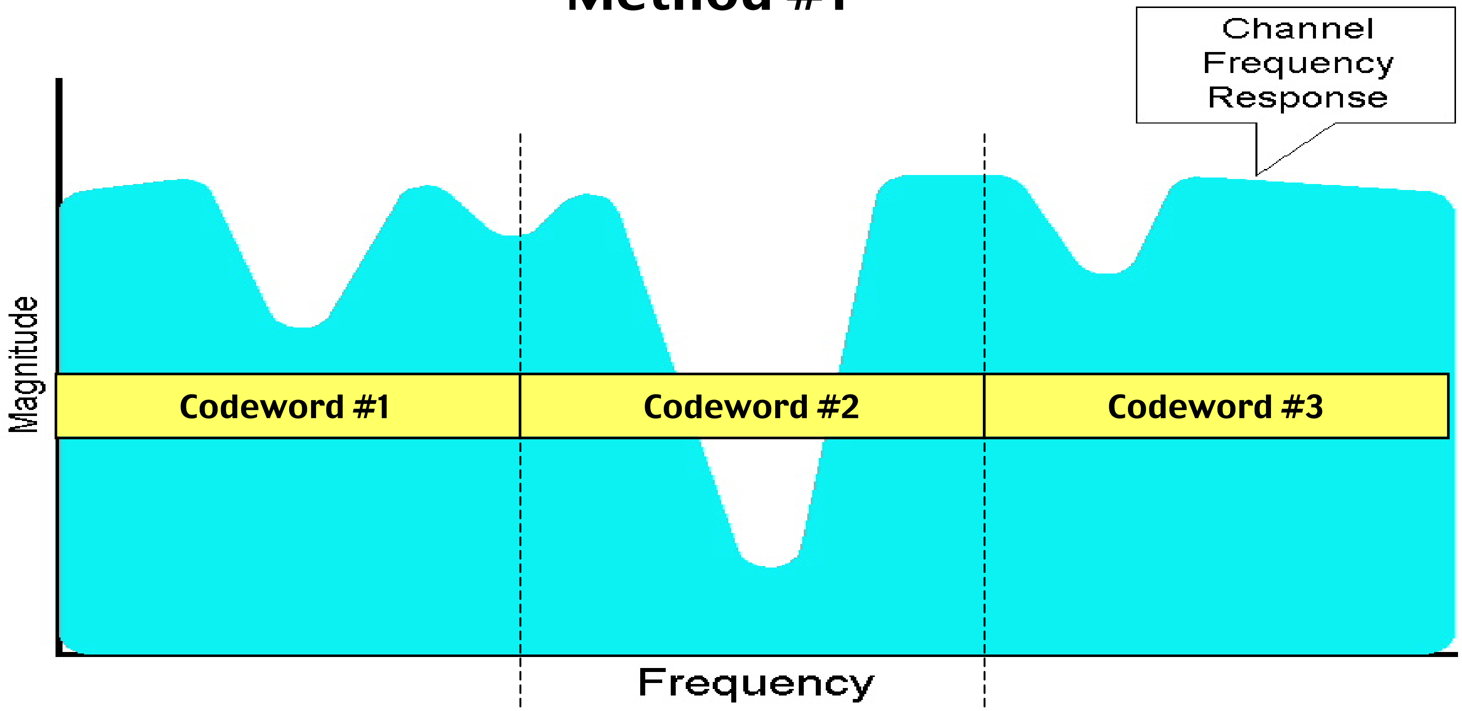
Reed-Solomon as Forward Error Correction

- Errors due to multipath or interference are likely to be "bursty" and as RS is a block oriented correction scheme, it is well suited for the job!

- The correction power of RS can be enhanced with erasures. The channel estimation can be exploited to determine which Reed-Solomon symbols are likely to be in error.

Codeword Selection

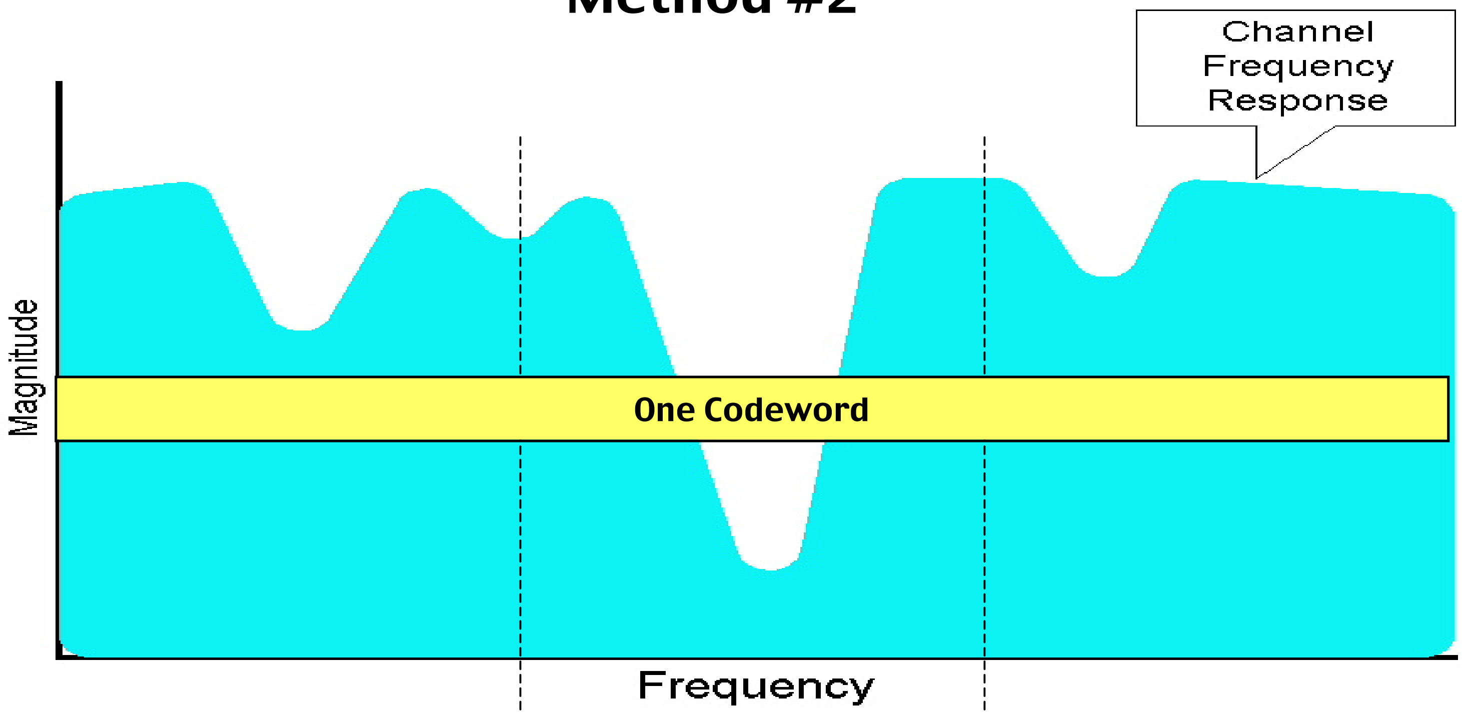
Method #1



- Not best solution
  - Not all codewords are equal.
  - Codeword #2 becomes a “weak link”!
  - Correction Power in Codeword #3 is wasted.

Codeword Selection

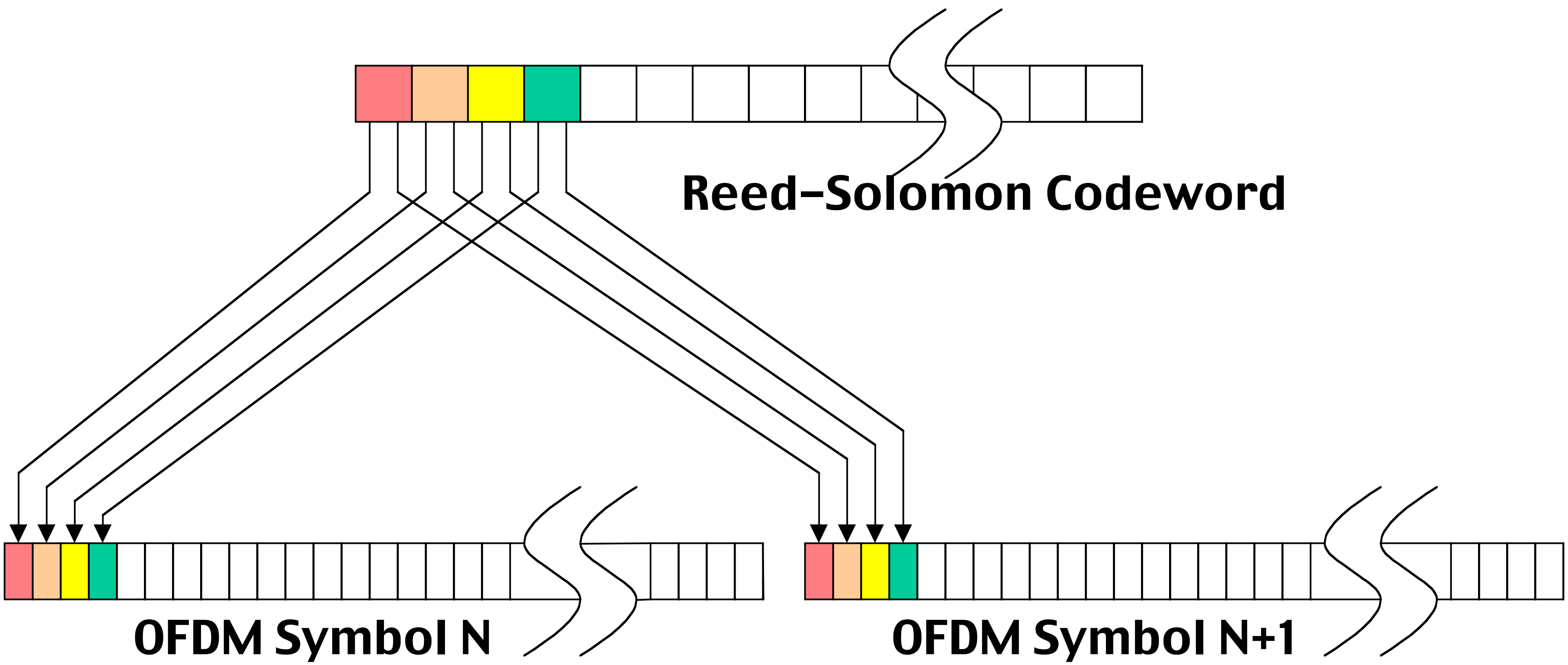
Method #2



- **Best solution**
  - **One codeword encompasses entire channel.**
  - **All codewords are "equal".**
  - **All of the strong sub carriers can help out the weak ones.**

Interleaving

for 16-QAM
with 8-bit RS symbols



Mapping

- Recommend several mapping schemes to optimize data rate and provide quality of service.

- Mandatory
  - BPSK
  - QPSK
  - 16-QAM

- Optional
  - 64-QAM
  - 256-QAM

Pilot Inserting

- Pilots are inserted to provide constellation reference points for the receiver.

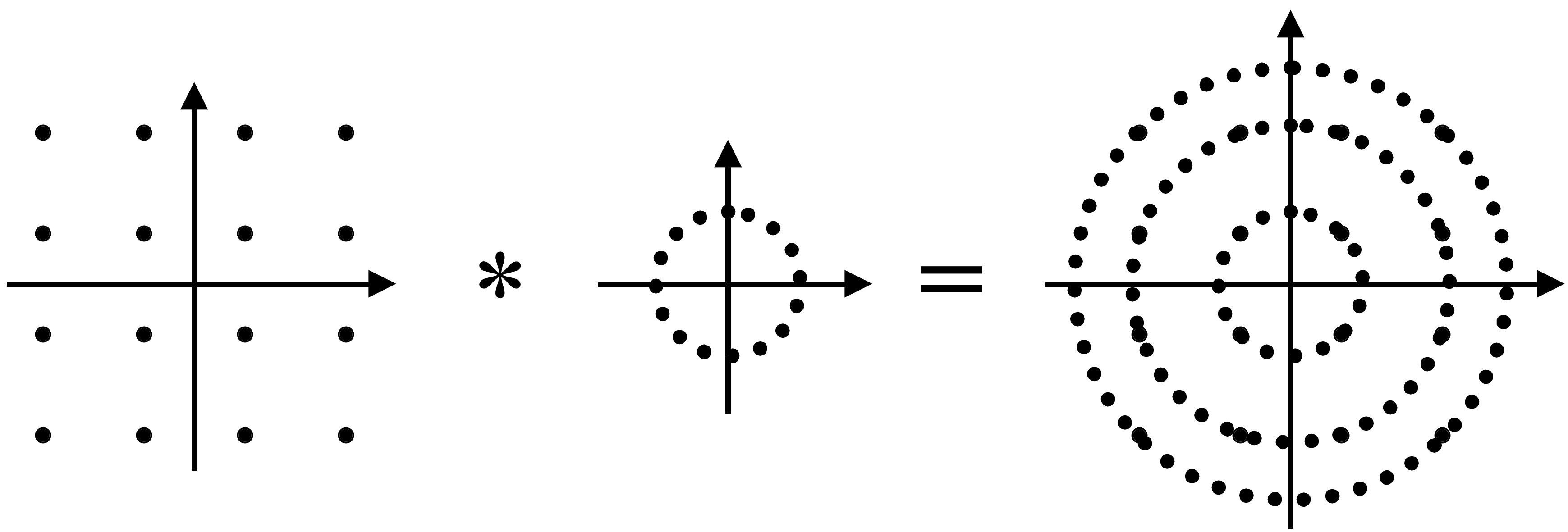
- They are used to undo any phase rotation caused by RF carrier offsets.

Random Phase Generation

- Random phase vectors are used to minimize problems due to Peak-to-Average Power Ratio PAPR.
- They should be changed between successive transmissions to prevent any bad PAPRs from reoccurring.
- The random phase vectors are also used for training.

Signal Whitening

- Each mapped constellation point is multiplied by a random phase.



Inverse FFT

- Translates the frequency-domain mapped code-words into time-domain OFDM symbols for RF transmission.

- Creates the orthogonal multiplexed sine waves.

- Recommend a size of 64 or 256 depending on requirements such as:
  - Data Rates
  - Channel Size
  - Channel delay spread
  - QoS

Cyclic Extending

- Copy a piece of the time-domain OFDM symbol from one end to the other.

- Adds a guard interval to prevent inter-symbol interference caused by multipath delays.

- Length of cyclic extension should be governed by the delay spread of the channel.

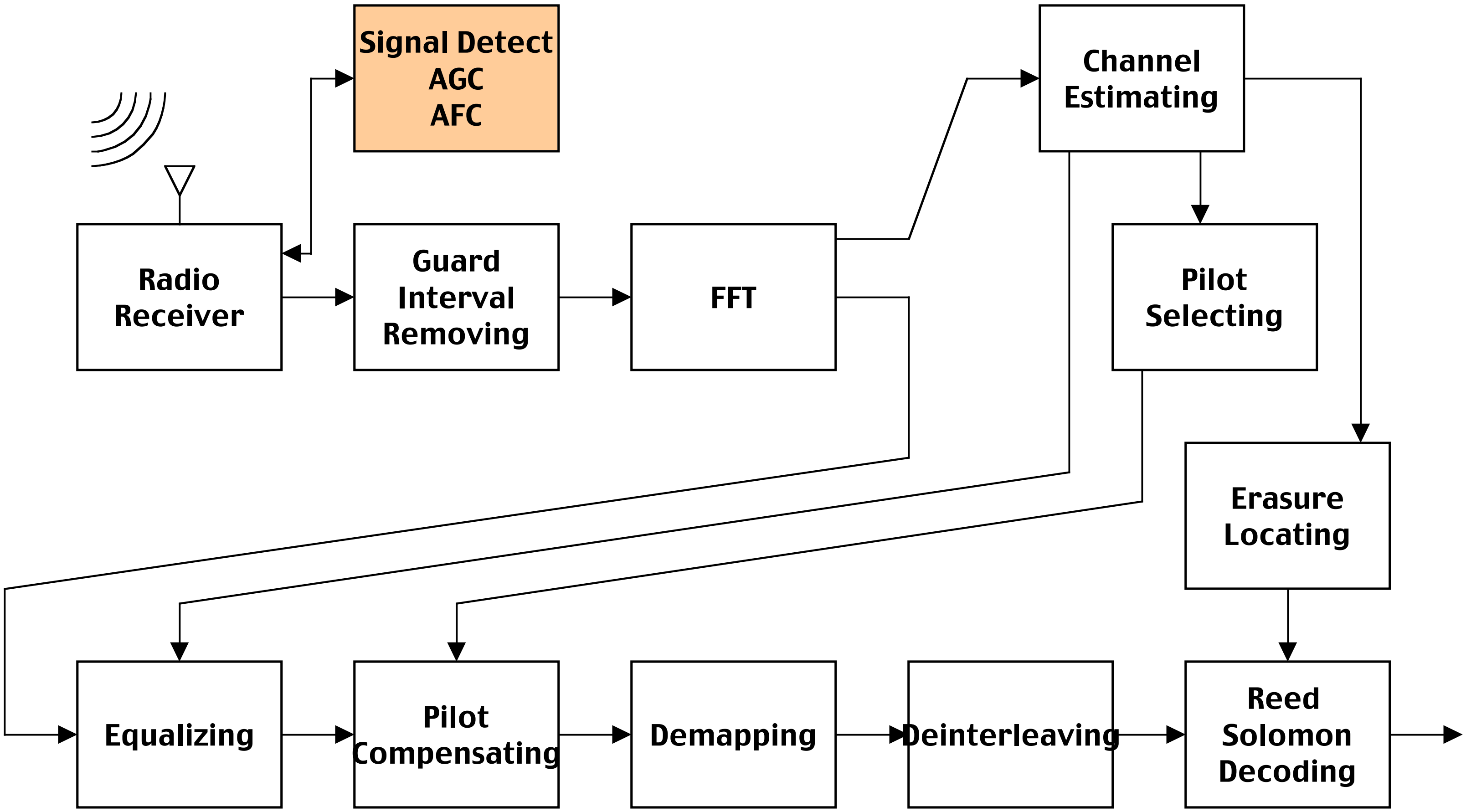
Preamble

- A preamble is added to each transmission.

- The receiver uses the preamble for:
  - Automatic Gain Control (AGC)
  - Synchronization
  - Carrier Frequency Compensation

- Preamble can also be used to signal certain PHY parameters such as:
  - Guard Interval
  - Mapping

OFDM Receiver



Receiver

- **Guard Interval Removal:**
  - Simply a sampling window issue
  - Starting point is a known offset from sync point
  - For each OFDM symbol, N samples are processed, then the cyclic extension samples are discarded.

- **FFT:**
  - Simply the inverse of the inverse FFT

- **Demapping and Deinterleaving:**
  - Simply the inverse of mapping and interleaving

Channel Estimation and Equalization

- This is what makes OFDM such an elegant solution.
- The training symbols are used to determine the channel estimation and create the equalization vector.
- Equalization restores the relative positions of the mapped constellation points so that they are easy to de-map.
- By using the random phase vectors as the training, this step also un-whitens the signal.

Erasure Locating

- This is a benefit of using Reed–Solomon.
- It allows valuable information from the channel estimation to be exploited to increase the correcting capability of the Reed–Solomon decoder.

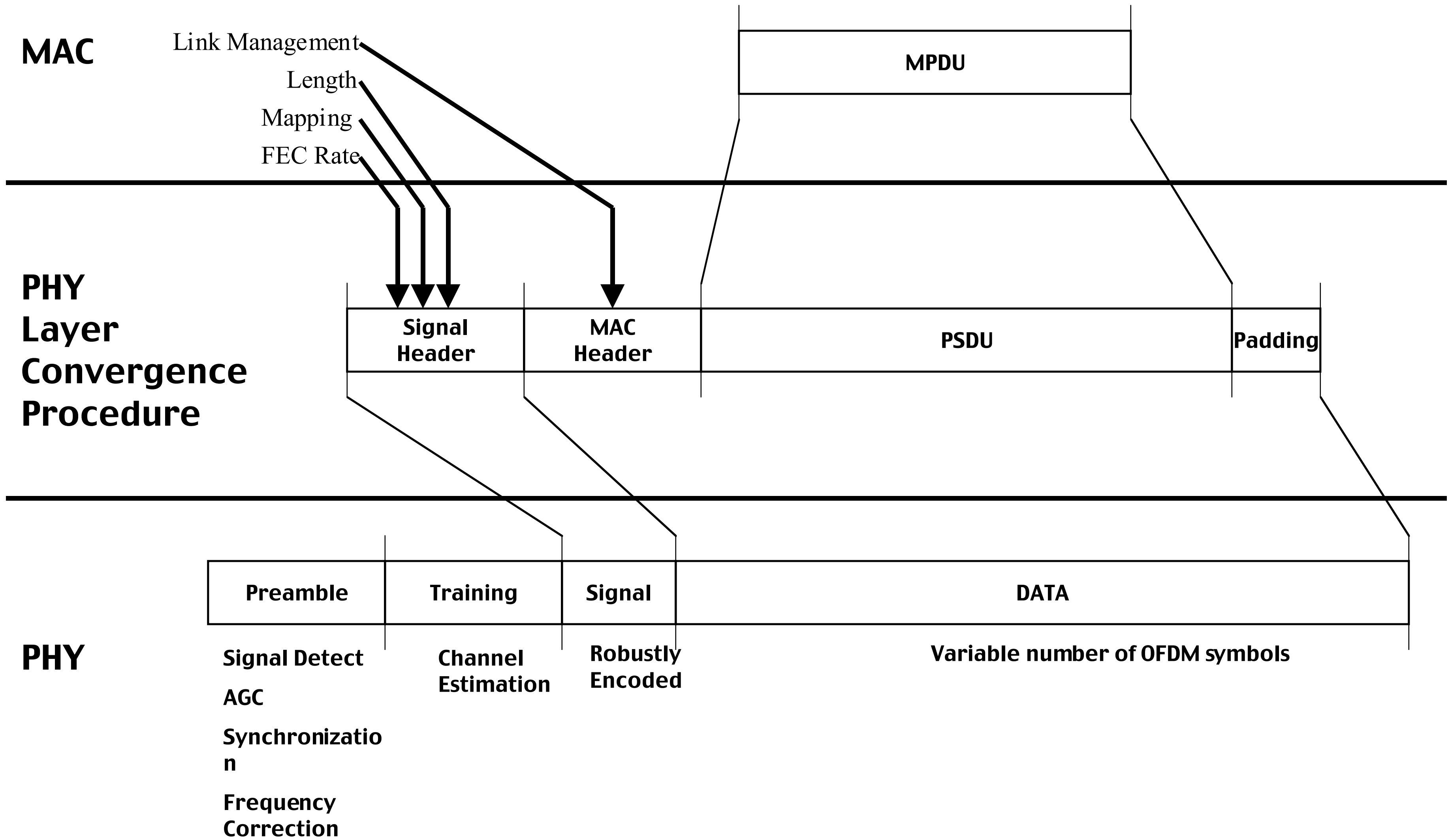
Upper Layer Interfaces

- The MAC should send the following to the PHY:
  - Data Length
  - Data
  - Modulation (Mapping) Rate
  - FEC Rate
  - Tx Power
  - Tx Time
  - Tx Center Frequency
  - Rx Center Frequency

Upper Layer Interfaces

- The PHY should send the following to the MAC:
  - Data Length
  - Data
  - RSSI
  - Rx Time

OFDM Frame Format



Highlights

- OFDM is spectrally efficient
- Simplicity of Implementation
  - OFDM elegantly accounts for RF channel impairments
  - There are existing OFDM standards
- Flexible Spectrum Usage
  - FDD or TDD
- Very robust to channel impairments
- Robust to narrowband interference
- Can support advanced antenna techniques