Research Consortium in Speckled Computing

OFDM and OFDMA for Specknets

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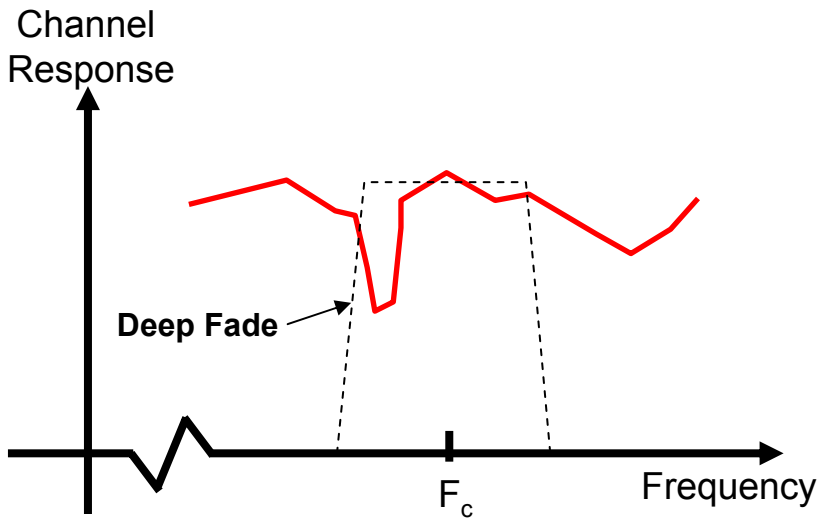
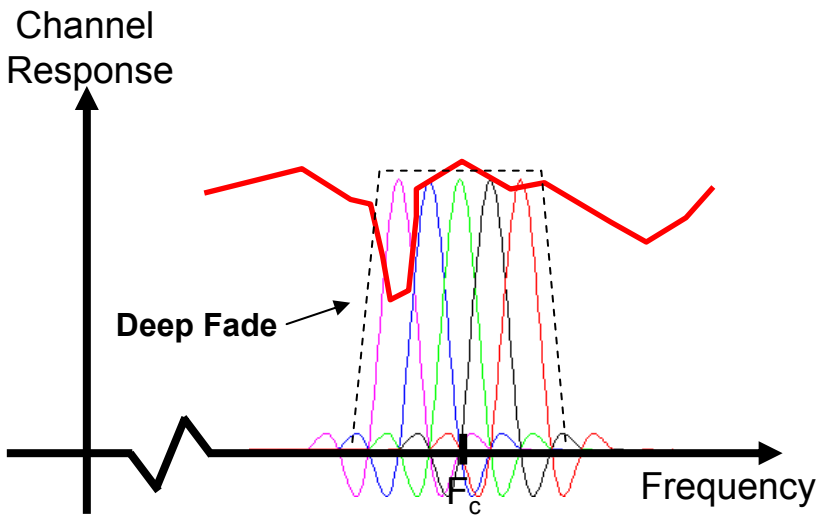
Introduction

- Orthogonal Frequency Division Multiplexing
- OFDM in a Specknet Physical Layer
- OFDM as a multiple access technology
- Orthogonal Frequency Division Multiple Access
- Multiple Access Interference analysis
- Conclusions and Further Work

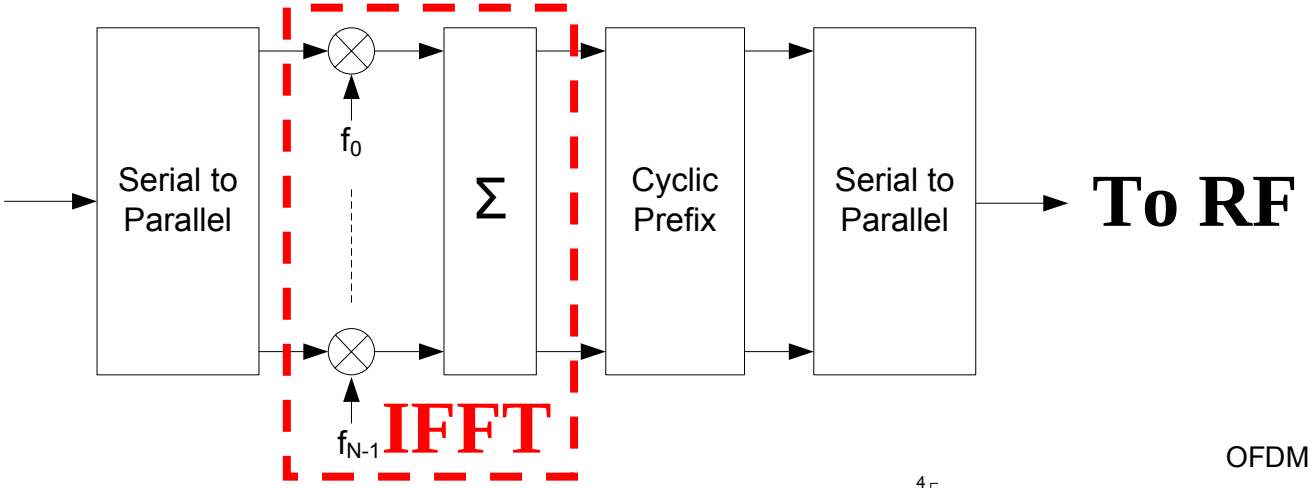
Orthogonal Frequency Division Multiplexing

- Becoming very popular technology
- In PHY specifications for ADSL, DVB, DAB, UWB, 802.11a,g, 802.15.3, WiMax…
- Divides a wideband frequency-selective channel into several narrowband flat-fading channels

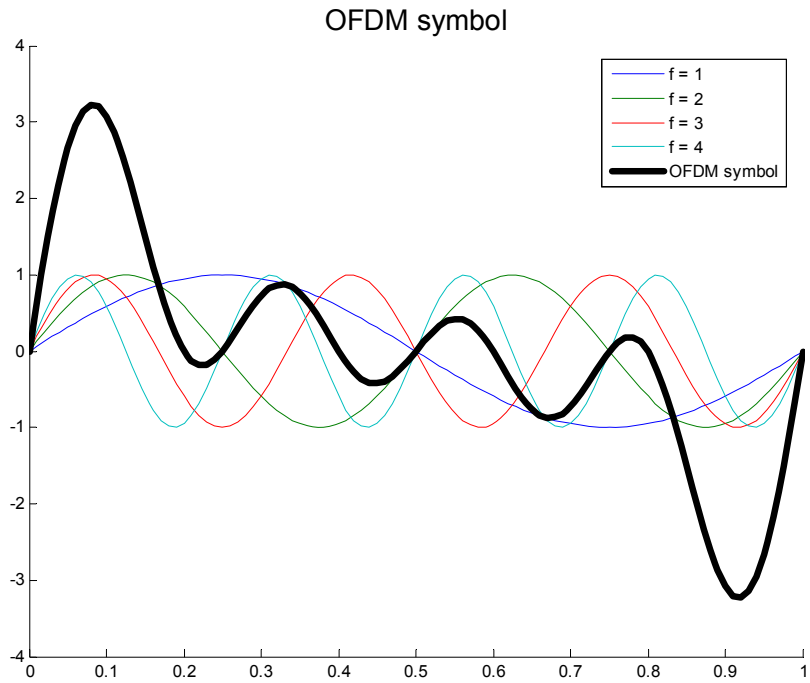




OFDM system



- Full speed data stream split up into multiple lower-speed streams
- Placed onto orthogonal carriers using IFFT
- Demodulation is reverse process (FFT)

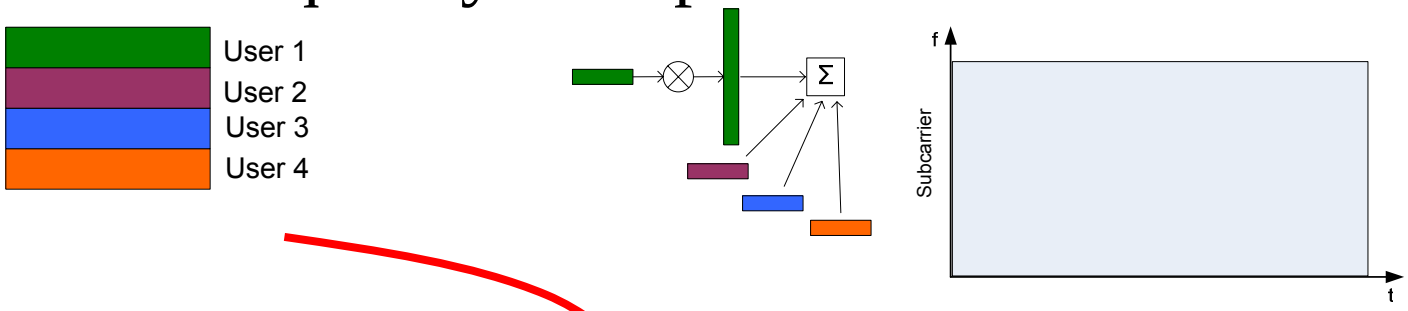


OFDM in a Specknet channel?

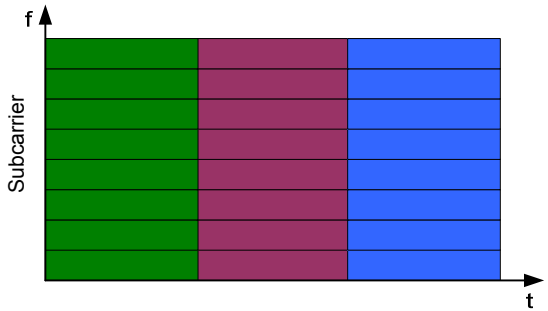
- OFDM is most useful in a channel with significant multipath
  - Multipath becomes significant as data rates and distance increase.
  - For a significant channel to be seen at ~10cm, data rates would have to be of the order of Gbps.
- Simple conclusion is that OFDM as a simple modulation technique is not worthwhile for a low-power radio transmitting over very short ranges.
- However, OFDM can also be a multiple access enabler, where each user is assigned subcarriers

OFDM as a MAC technology

- OFDM can be used to create a code, time or frequency multiple access scheme



OFDM - CDMA

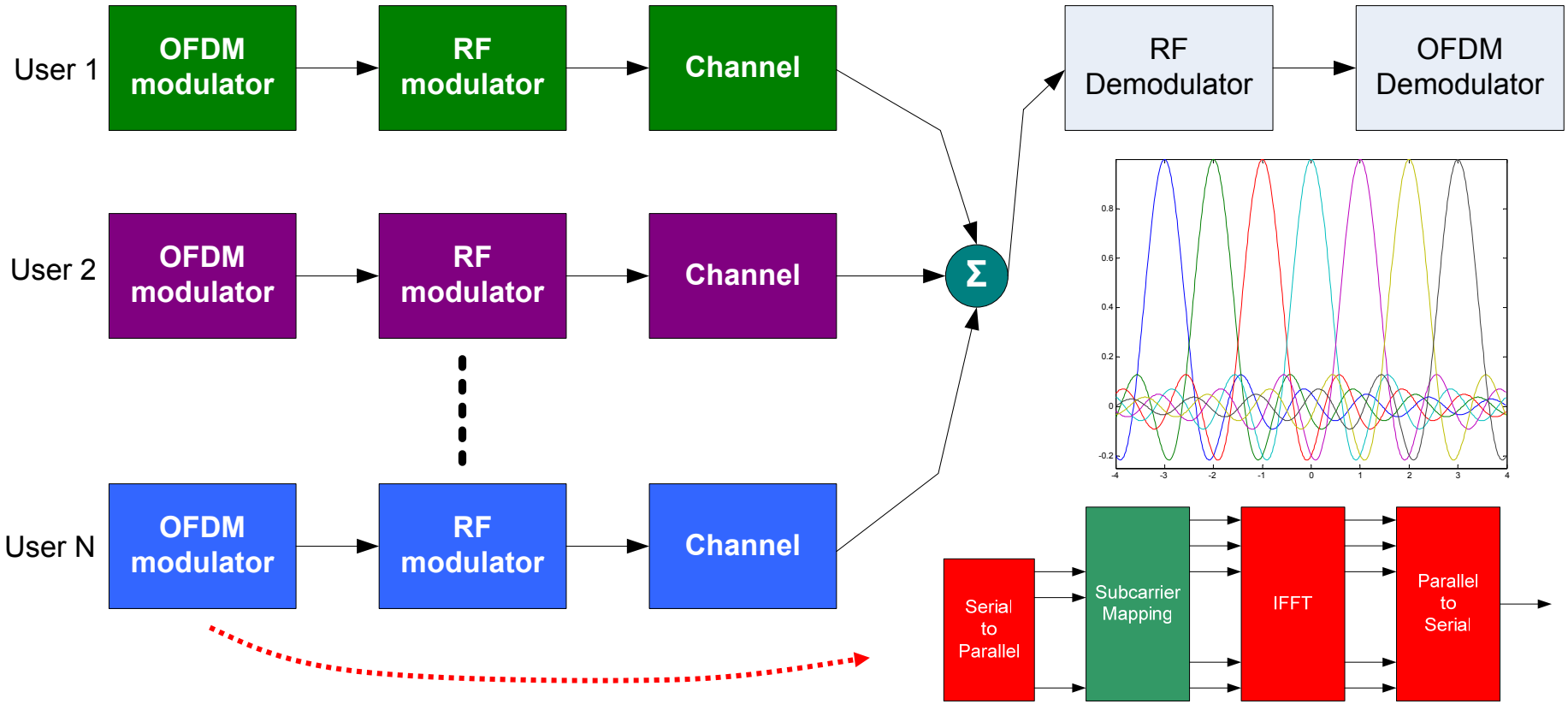


OFDM - TDMA

OFDM - FDMA

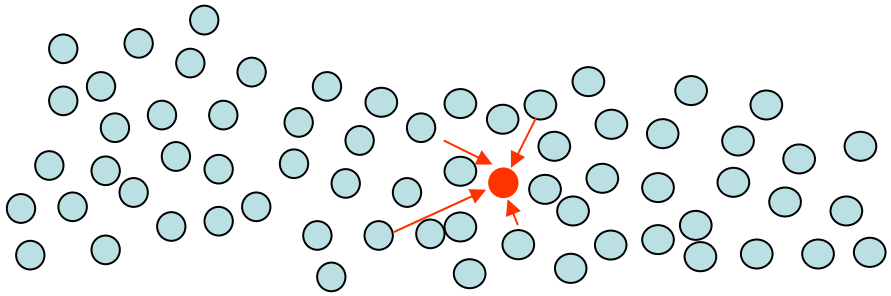
Orthogonal Frequency Division Multiple Access (OFDMA)

- The simplest of the OFDM multiple access techniques
  - Each user is allocated a number of orthogonal subcarriers
  - Extremely efficient use of spectrum, users overlap



OFDMA synchronisation problem

- Similar problem to CDMA
  - Tight time and frequency synchronisation must be maintained to preserve orthogonality of carriers
- OFDMA has mostly been used in synchronous channels (e.g. basestation to mobile downlink)
- Specknet is an asynchronous channel
  - Time and frequency offsets between users result in Multiple Access Interference (MAI)



Asynchronous OFDMA – time offsets

- Frequency offset problem is same as for any network
- The short-range, dense nature of a Specknet may minimise the degradational effect of time offsets
- The assumption:
    - *All transmitting specks transmit within some reasonable time period of each other*

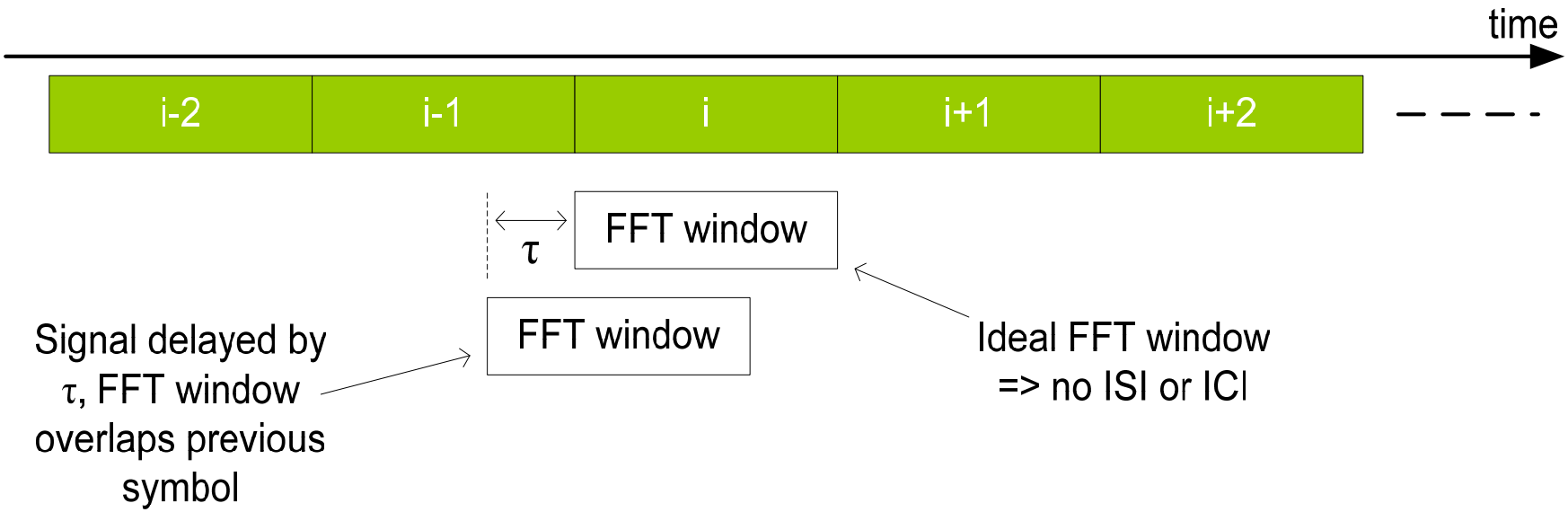
Minimal MAI due to time offsets

- The result:
  - Time offsets become equivalent to the propagation delay from the transmitter to the receiver
  - In a Specknet, propagation delays are very small

  - MAI due to time offsets is minimal?
  - Synchronisation requirements can be relaxed?

MAI in OFDMA due to time offsets

- A loss of time synchronisation results in inter-carrier and inter-symbol (ICI,ISI) interference



- Not considering any time guard (cyclic prefix)

The demodulated signal

$$Y_{m,i} = \frac{1}{T_s} \sum_{n=0}^{Nc-1} \rho_n \int_0^{Ts} \sum_{i'=-\infty}^{\infty} C_{n,i} e^{j2\pi f_n (t - i'Ts - \tau_n)} e^{j2\pi f_m (t - iTs)} dt$$

Decision variable for symbol on subcarrier m, time i

Attenuation in channel n

Receiver FFT

Symbol transmitted on subcarrier n, OFDM symbol i

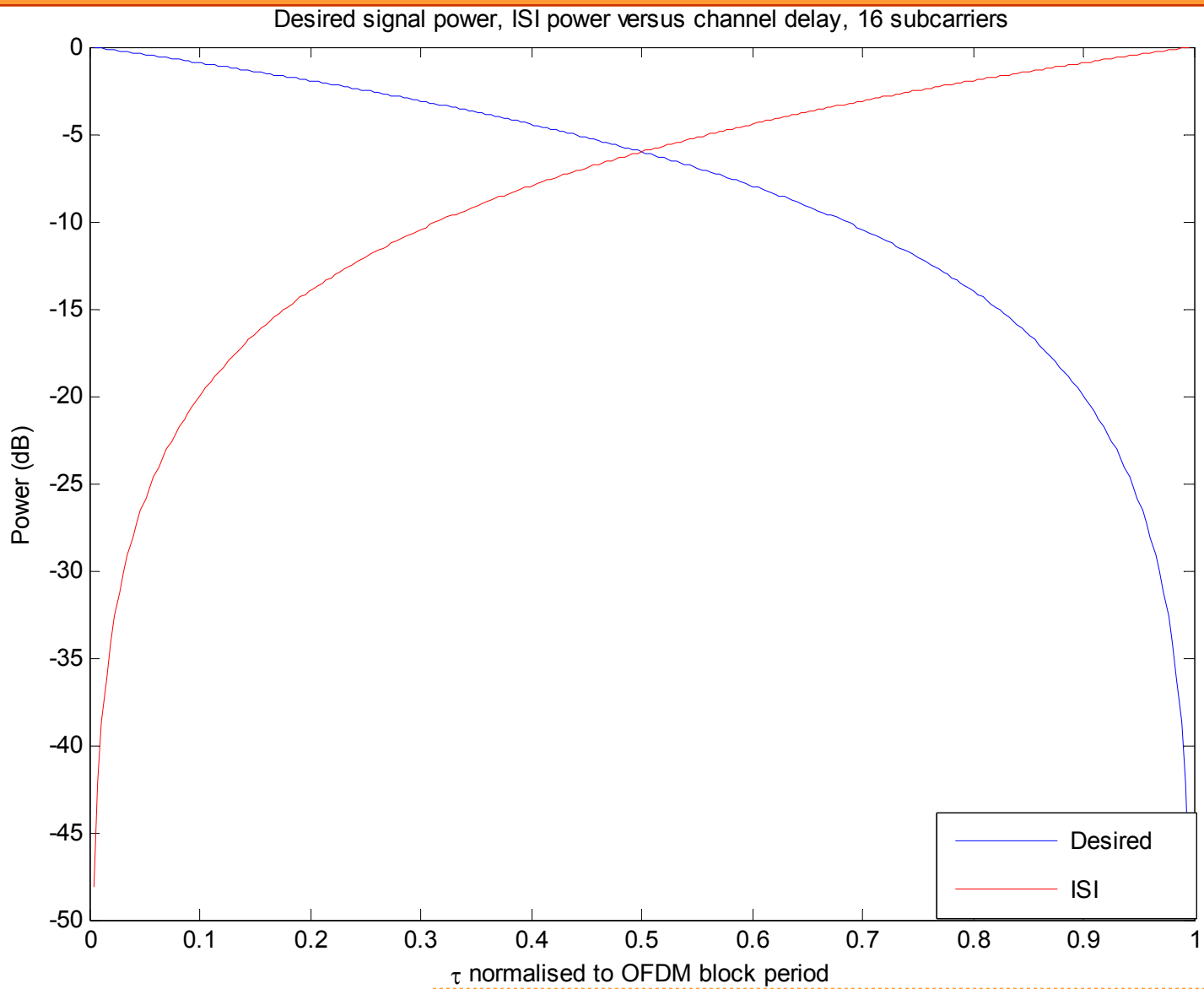
Transmitted subcarrier n, OFDM symbol i

Prop. delay on channel n

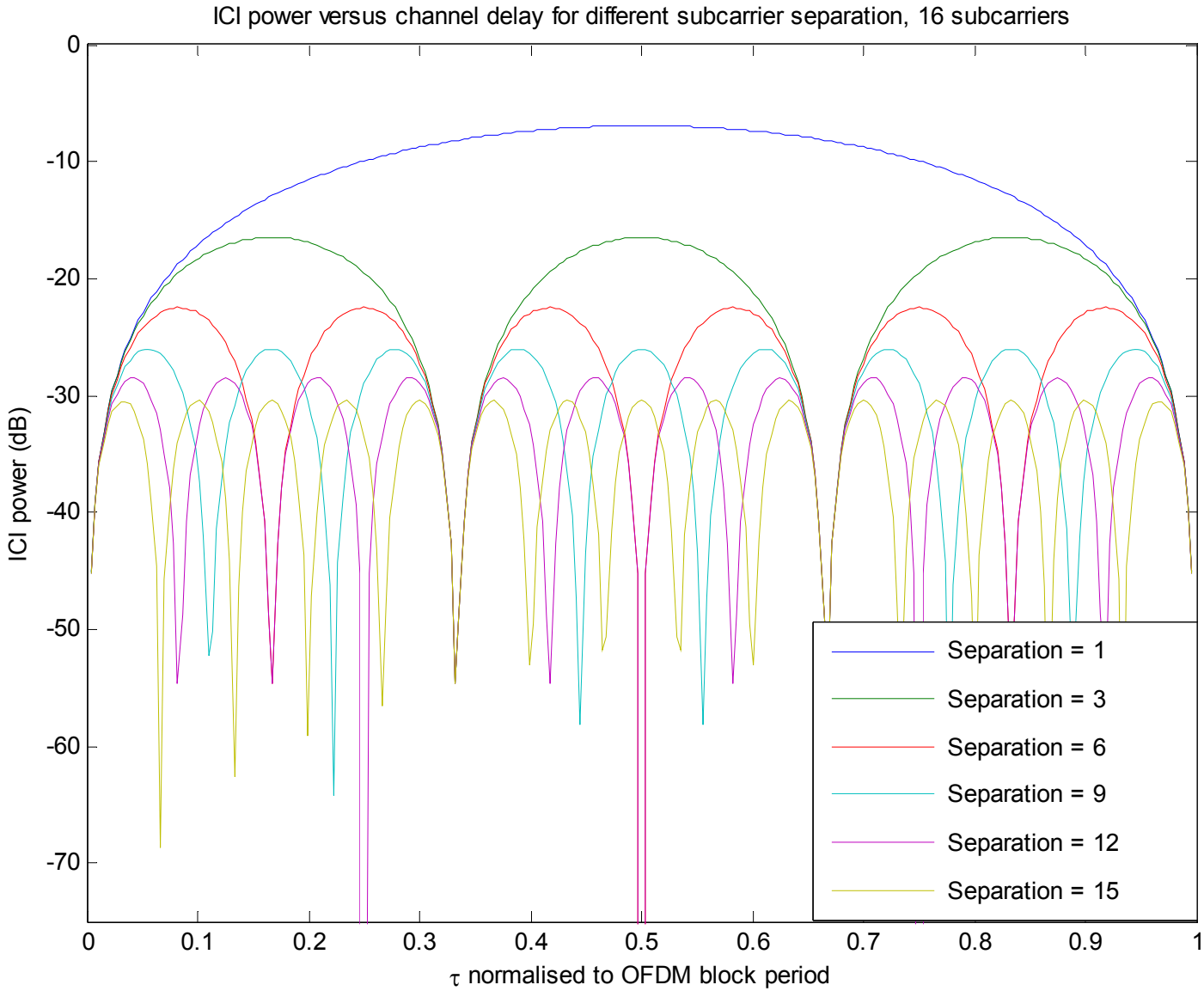
Receiver FFT

- Disregarding noise, consists of 3 components:
  - Desired info, ICI from other subcarriers (users) and ISI from desired subcarrier (desired user)

Desired and ISI power



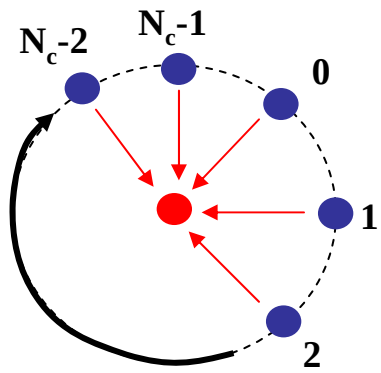
ICI from different subcarriers



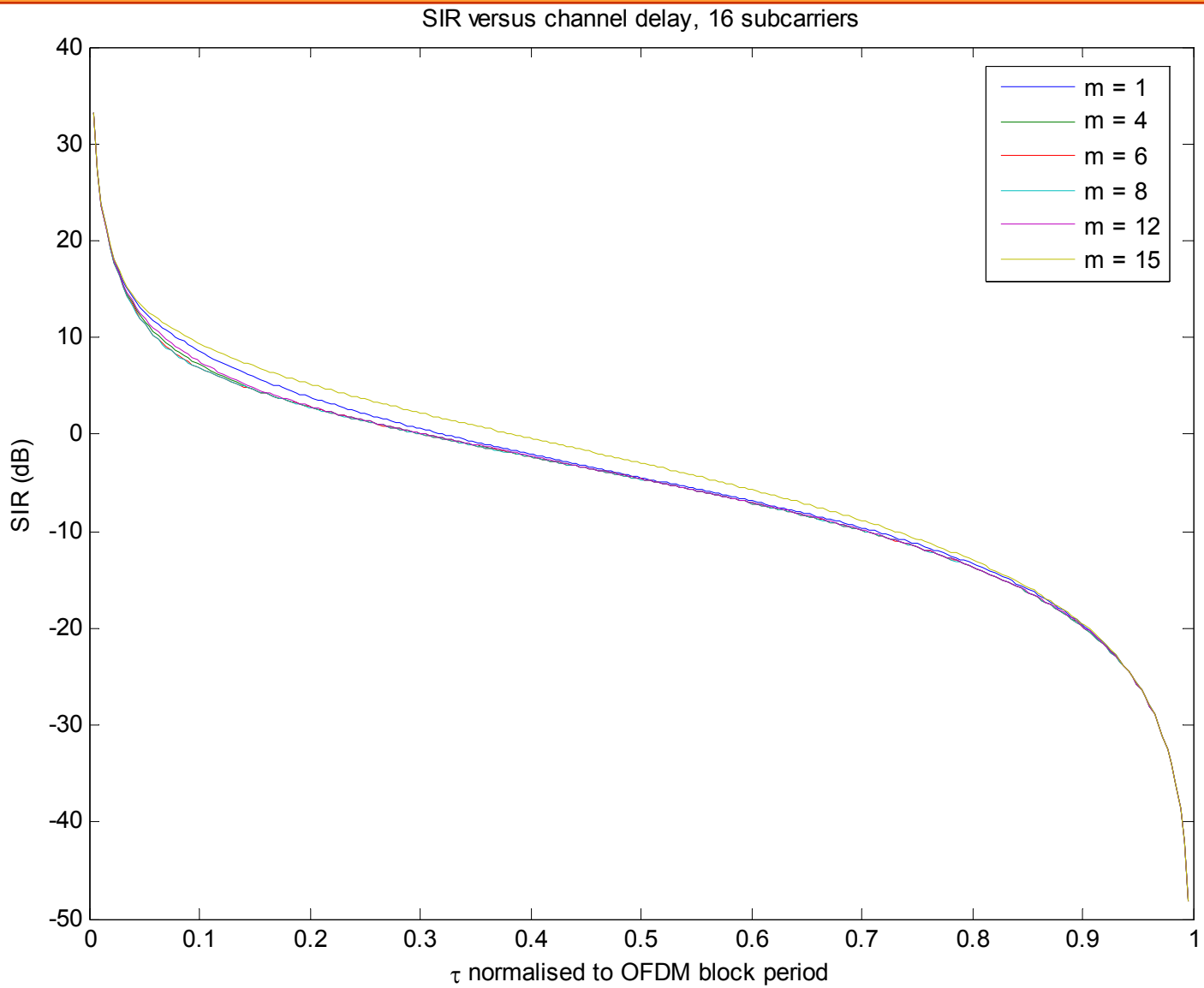
Signal to Interference Ratio (SIR)

- SIR gives the ratio of desired signal power to ISI and ICI power on a chosen subcarrier
- Assumptions:
  - All subcarriers are in phase, at the same distance from the receiver and the information symbols are statistically independent
  - Perfect power control / circular deployment and no noise

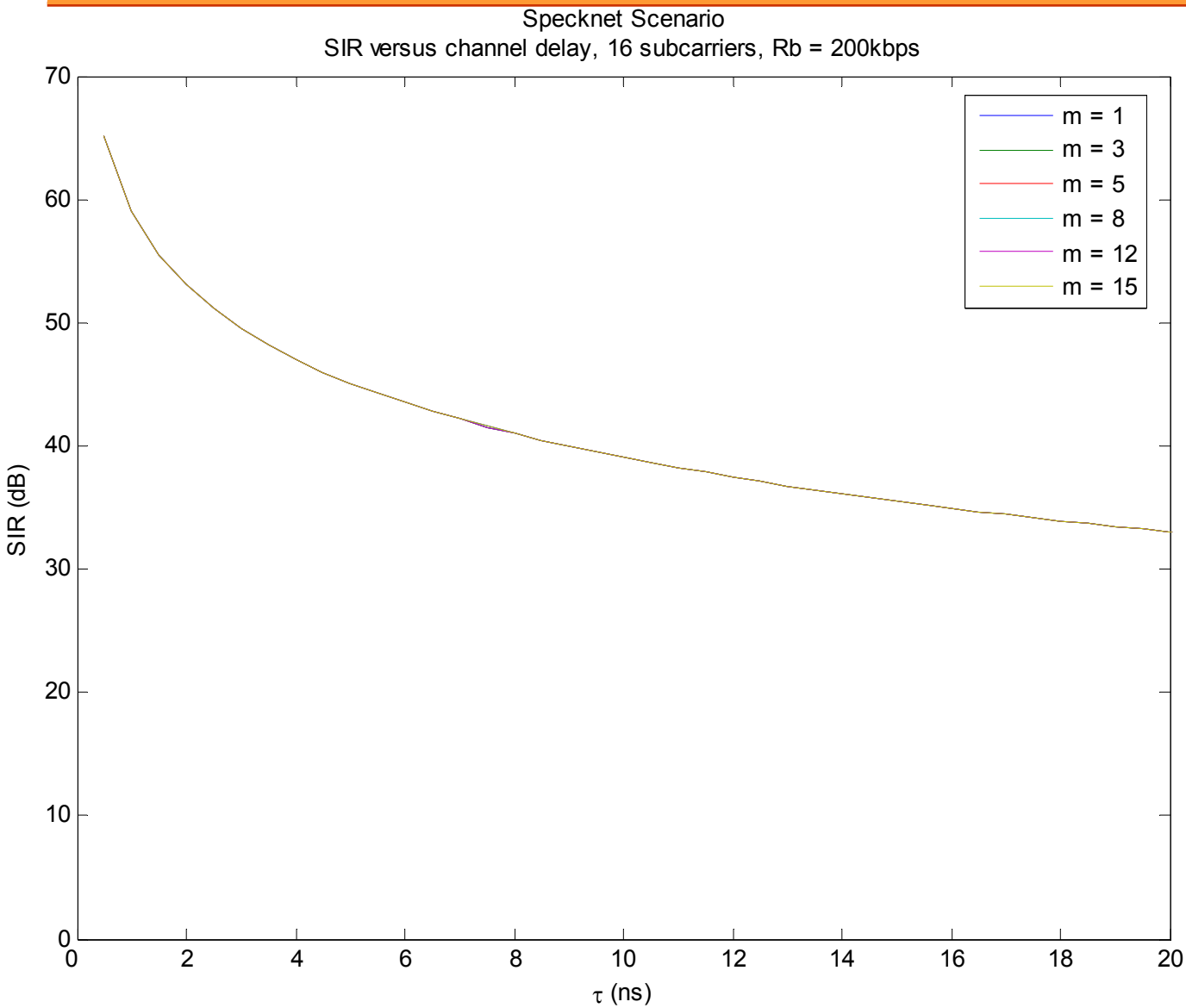
$$SIR_n = \frac{Ps}{P_{ISI} + P_{ICI}}$$



SIR

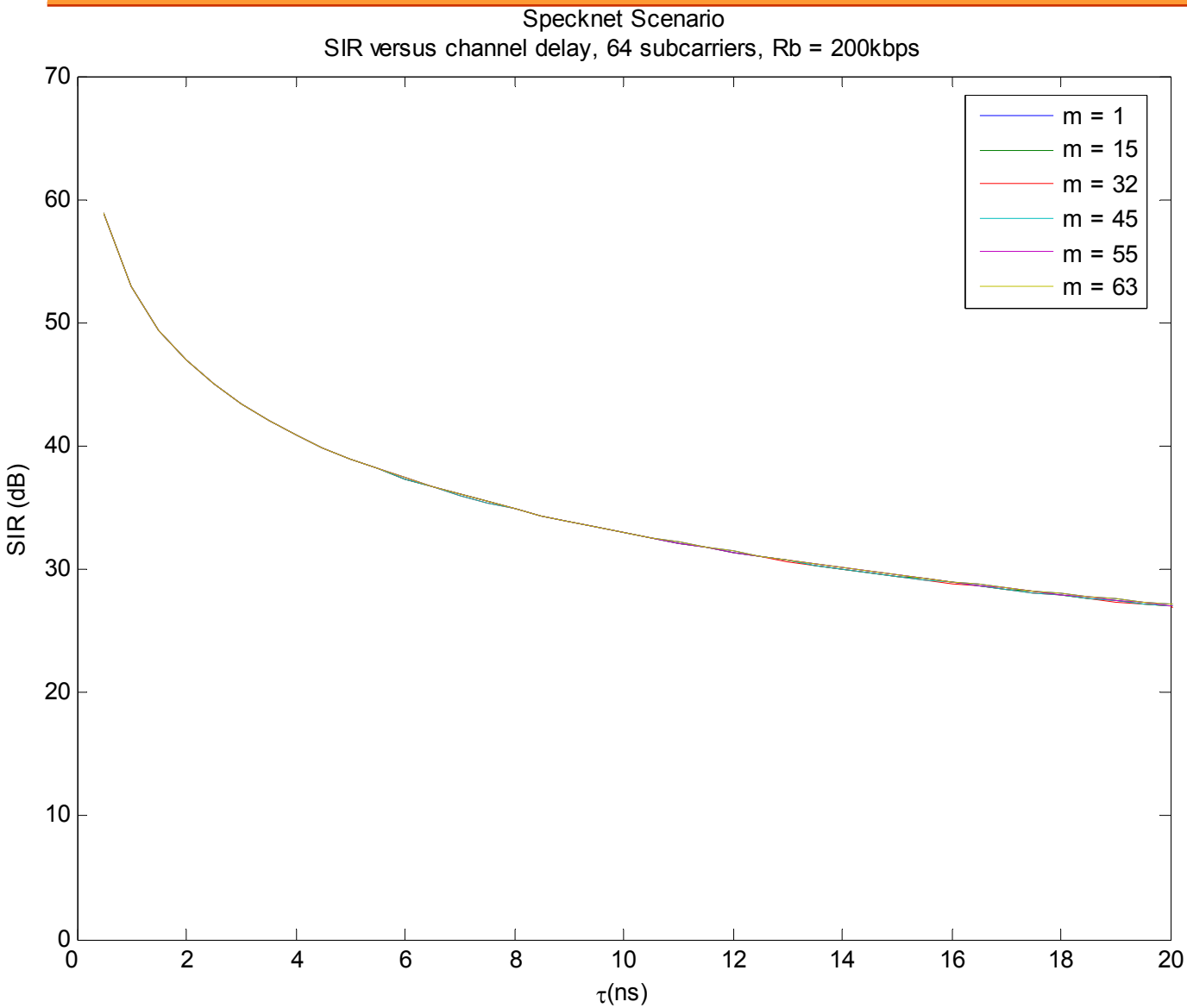

SIR versus channel delay, 16 subcarriers
SIR (dB)
τ normalised to OFDM block period
m = 1
m = 4
m = 6
m = 8
m = 12
m = 15
40
30
20
10
0
-10
-20
-30
-40
-50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Specknet scenario SIR



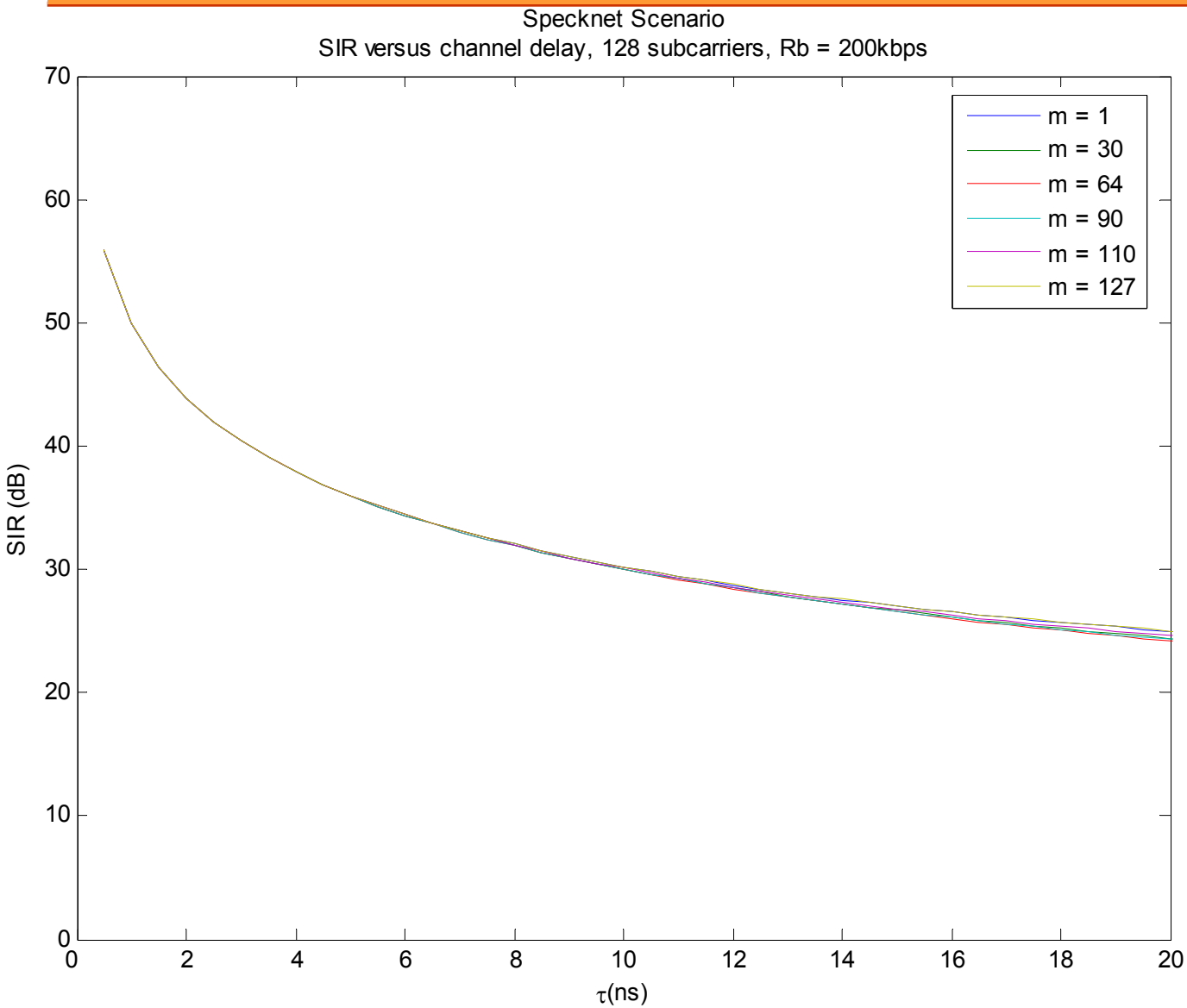
16 carriers
Bit rate = 200kbps

Specknet scenario SIR



64 carriers
Bit rate = 200kbps

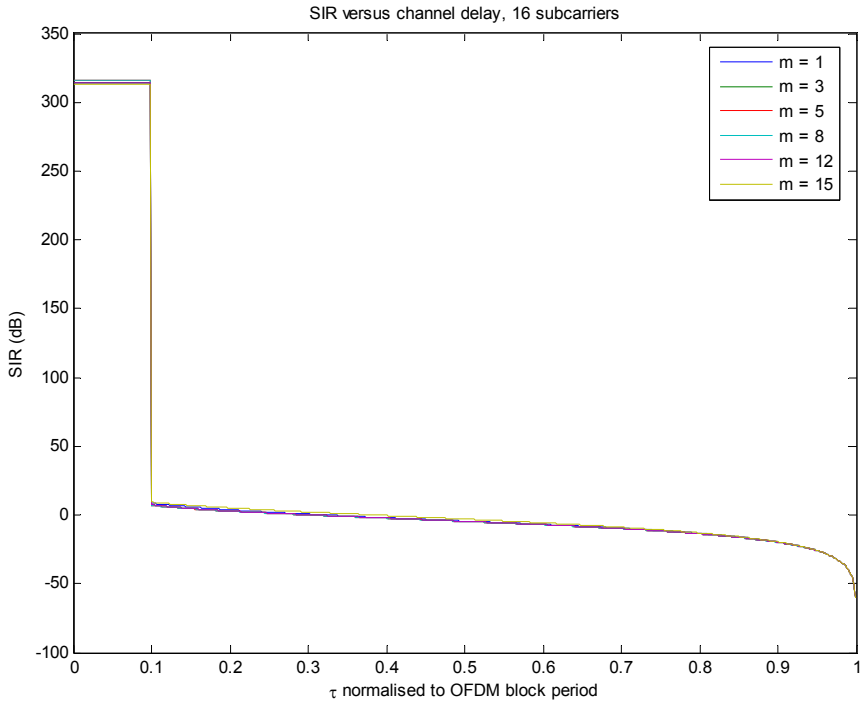
Specknet scenario SIR

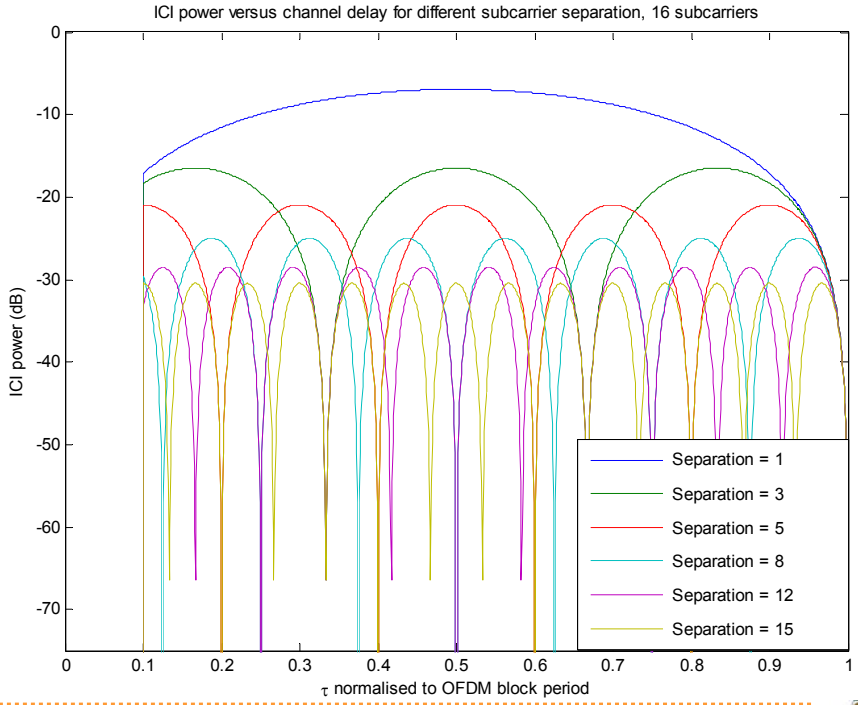


128 carriers
Bit rate = 200kbps

Cyclic Prefix

- *The MAI introduced by time offsets can be completely removed by inserting a guard time between OFDM symbols that is longer than the maximum time offset*





Conclusions

- OFDM is becoming an extremely popular modulation technique
  - Mitigates multipath and allows increasing data rates
  - Specknet multipath is almost negligible

- Physical layer perspective :
  - Low data rates and short distances are unique to Specknet
  - Technologies which are prohibitively complex in other networks may be implementable in a Specknet

Conclusions

- OFDMA
  - MAI is caused by a combination of ISI and ICI
  - ISI and ICI are caused by time offsets to the FFT window
  - Time offsets in a Specknet could be minimal
- SIR
  - Combination of ISI and ICI
  - Remains high in a likely Specknet scenario

Future Work

- Strip away the assumptions
  - Variable channel (delay and attenuation) for each user
    - Realistic Speck deployment
  - Analyse frequency offsets
  - Time guard / Cyclic prefix
  - Power control

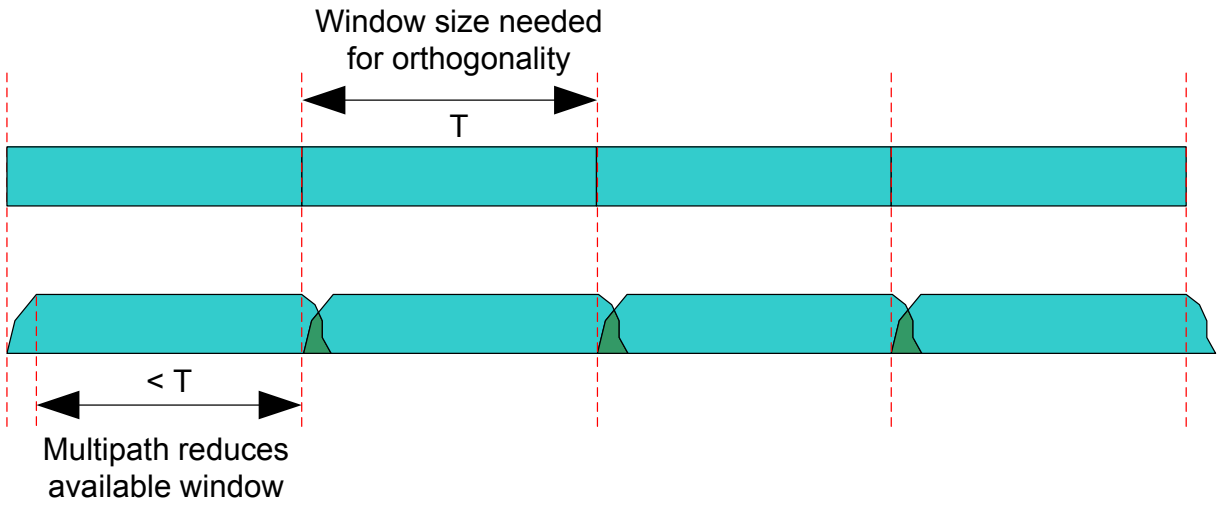
- Longer term: OFDMA transceiver
  - Minimise complexity

Questions?

Thank you!

The great advantage of OFDM – mitigates multipath

- Multipaths introduce transient regions at start and end of symbol
  - Within transient regions the frequency and phase of the carriers are altered so that they are no longer orthogonal
  - The FFT in the receiver must be performed over window of T seconds where amplitude and phase are constant



Cyclic Prefix

- Common to add a cyclic prefix to an OFDM symbol
  - Last N samples of the symbol are prepended
  - Mitigates inter-symbol interference
  - Greatly simplifies receiver synchronisation and equalisation