What I’m going to talk about

OSI Abstract Network Model

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

How bits are represented “over the air” and why
Our goal: Replace the best LAN (Local-Area Network) technology available at that time with a wireless equivalent

Requirements:

- fast (~100 Mbps)
- wireless
- works indoors
- short(-ish) range is OK
A Basic Digital Modulation: QPSK

4 symbols: \( s_k(t) = \sqrt{2} \cos(\omega t + \phi_k), \quad \phi_k = 45^\circ, 135^\circ, 225^\circ, 315^\circ \)

\[ s_0(t) = \cos(\omega t) - \sin(\omega t) \]
\[ s_1(t) = -\cos(\omega t) - \sin(\omega t) \]
\[ s_2(t) = -\cos(\omega t) + \sin(\omega t) \]
\[ s_3(t) = \cos(\omega t) + \sin(\omega t) \]

Spectral efficiency: 2 bits/sec/Hz i.e. 1 symbol/sec/Hz
via cable/fibre

100 Mbps?
via cable/fibre

in free space

100 Mbps ?

✓
via cable/fibre

in free space

pencil beam

100 Mbps?
CSIRO Lindfield site aggregation proposal

~2 Mbps
The problem is Multipath
Two copies arrive and overlap

Signal

Potential interference

Time via path 1

via path 2

Impulse Response

~ 50 - 300 ns

Delay Spread

Sum

Signal Amplitude

potential interference
There are many paths in practice
Effect of Multi-path on QPSK symbols

Channel Impulse Response

QPSK symbol sent

received

Delay Spread ~ 50 - 300 ns

20 ns

time
Effect of Multi-path on QPSK symbols

Channel Impulse Response

QPSK symbol sent

received

symbol stream

ISI

Delay Spread ~ 50 - 300 ns

20 ns
Effect of Multi-path on QPSK symbols

Delay Spread
~ 50 - 300 ns

Channel Impulse Response

QPSK symbol sent

received

symbol stream

ISI

Cyclic Extension

received

stable signal
Frequency Response of the Link
Frequency Response of the Link

( This is a Rayleigh process if there is no line-of-sight signal )
Frequency Response of the Link

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Frequency Response of the Link

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Frequency Response of the Link

- Amplitude (dB)
- Frequency

Approximately 10 dB
- $\sim \frac{1}{T_{\text{delay spread}}}$

Signal Cancellations
Effect of Frequency Response

100 Mbps QPSK

50 MHz
Effect of Frequency Response

Idea: place narrow-bandwidth signals to avoid nulls
Placing the channels
Sending at N frequencies
Choosing the frequencies

Idea: Place streams at clear parts of the spectrum
Choosing the frequencies

Problem: large overhead to repeatedly measure the spectrum

Idea: Place streams at clear parts of the spectrum
A toy FEC (Forward Error Correction) Code
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Input Data: 011111000001111001

Coded Data: 011111100001111010011111100000111110010111111000001111101

Received Data: 011111100001111001011111100000111110010111111000001111101
A toy FEC (Forward Error Correction) Code

Input Data

Coded Data

Received Data

Corrected Data
Choosing the frequencies

Problem: large overhead to repeatedly measure the spectrum

Idea: Place streams at clear parts of the spectrum
Send coded signals instead

- Modulate on \( N + M \) channels
- FEC Coding
- Send \( N \) symbols
- Send \( N + M \) symbols
Send coded signals instead

Now we don’t ever have to measure the channel

Modulate on N + M channels

FEC Coding

N + M symbols

N symbols
How do we generate all the signals?

IFFT Implements N parallel QAM Modulators at regularly spaced frequencies

$e^{-j\pi/4}$

$e^{j(2\pi f_k t - \pi/4)}$
Multitone in the Time Domain

Channel Impulse Response

FFT symbol

received

Delay Spread ~ 50 – 300 ns

1 µs
Multitone in the Time Domain

Channel Impulse Response

FFT symbol

Delay Spread ~ 50 – 300 ns

received

FFT symbol with Cyclic Extension

1 µs
Multitone in the Time Domain

Channel Impulse Response

FFT symbol

Delay Spread ~ 50 – 300 ns

received

FFT symbol with Cyclic Extension

1 μs

1 μs

1 μs

time
Multitone in the Time Domain

Channel Impulse Response

FFT symbol

received

FFT symbol with Cyclic Extension

Delay Spread ~ 50 – 300 ns

1 µs
Simplified System
The Core Ideas

- **MTM** Multi-tone Modulation
  Multiplex the data stream into many slower streams and transmit them in parallel at different frequencies

- **FEC** Forward Error Correction
  Apply coding before transmission to prepare for losses
  *Never need to measure the channel*

- **FFT** Fast Fourier Transform
  Efficient generation of multi-tone modulation

- **CE** Cyclic Extension
  Corrects time-smearing of the multi-tone symbols
WiFi!