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I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

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ICTP - URSI - ITU/BDT WORKSHOP ON THE USE OF RADIO FOR DIGITAL COMMUNICATIONS IN DEVELOPING COUNTRIES

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Spread Spectrum Techniques and Applications

M.P. Fitton

Centre for Communications Research
University of Bristol
Bristol
UNITED KINGDOM

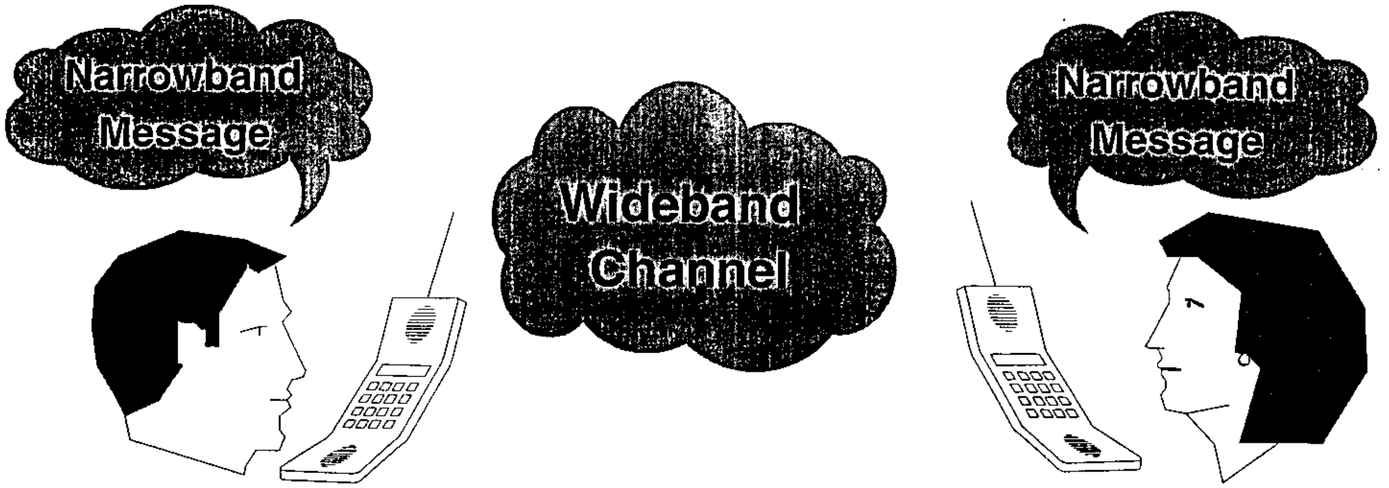
Spread Spectrum Techniques and Applications

M.P. Fitton,
Centre for Communications Research,
University of Bristol

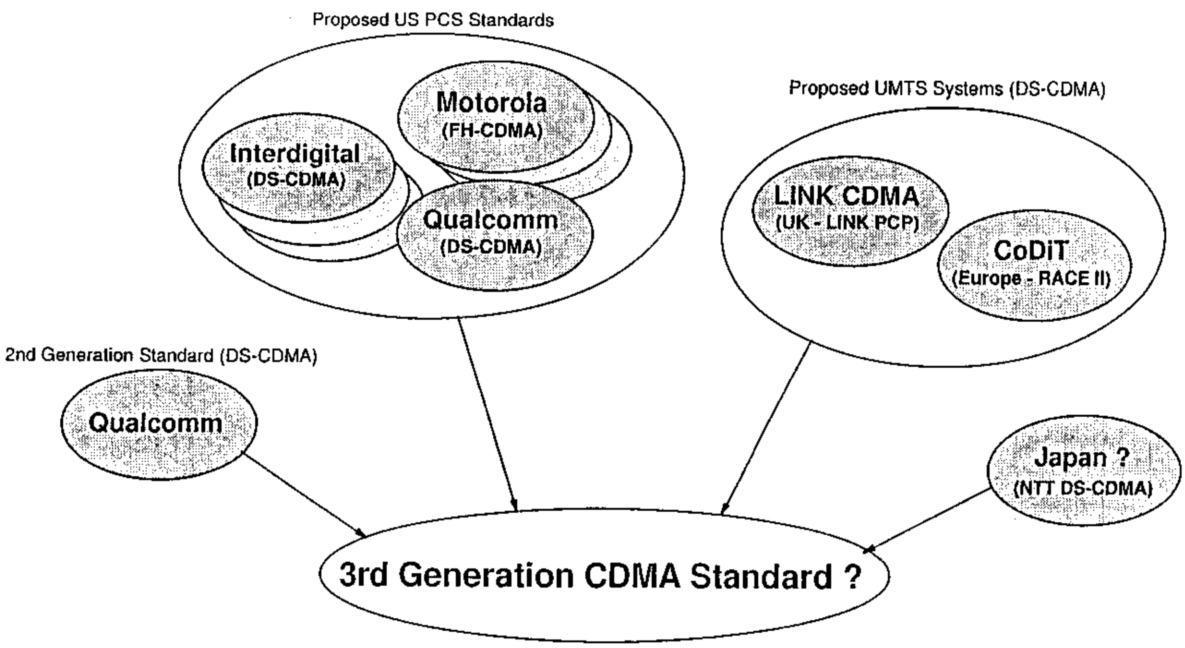
Summary of Spread Spectrum Techniques

- Spread Spectrum and Code Division Multiple Access (CDMA)
- Direct Sequence Spread Spectrum
  - Fundamentals
  - Improvement Techniques (RAKE receiver, soft handover)
  - Problems (near-far effect)
- Frequency Hopping Spread Spectrum
  - Fundamentals
  - Propagation and Implementation Issues
- Comparison of DS and FH-SS

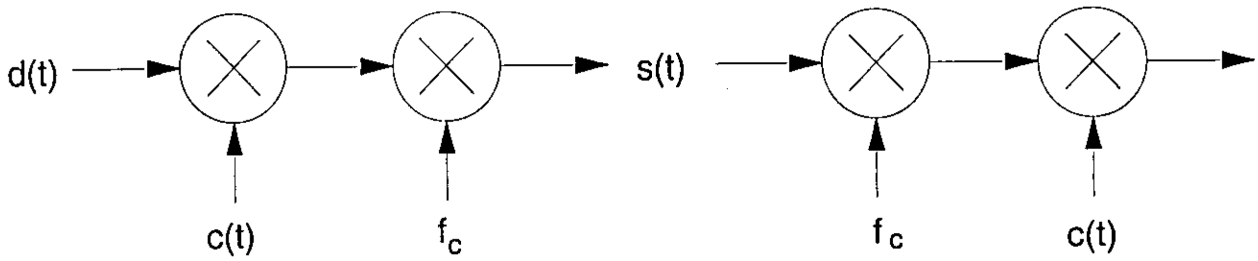
Spread Spectrum



CDMA Evolution

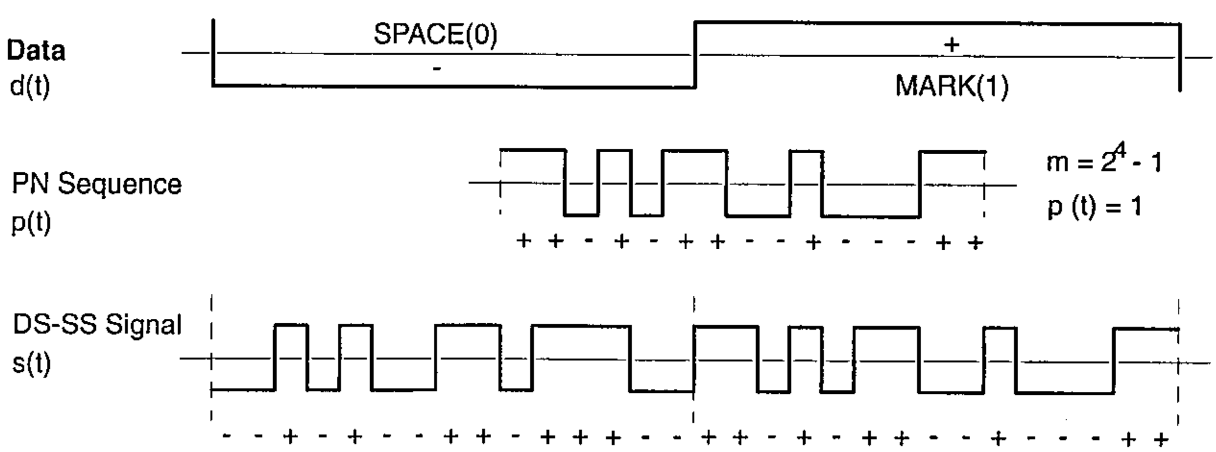


Direct-Sequence Spread Spectrum (DS/SS)



$$s(t) = d(t)\,c(t)\cos 2\pi f_c t$$
$$= d(t)\cos 2\pi f_c t\; c(t)$$

PN Spreading Code for DS-SS Systems

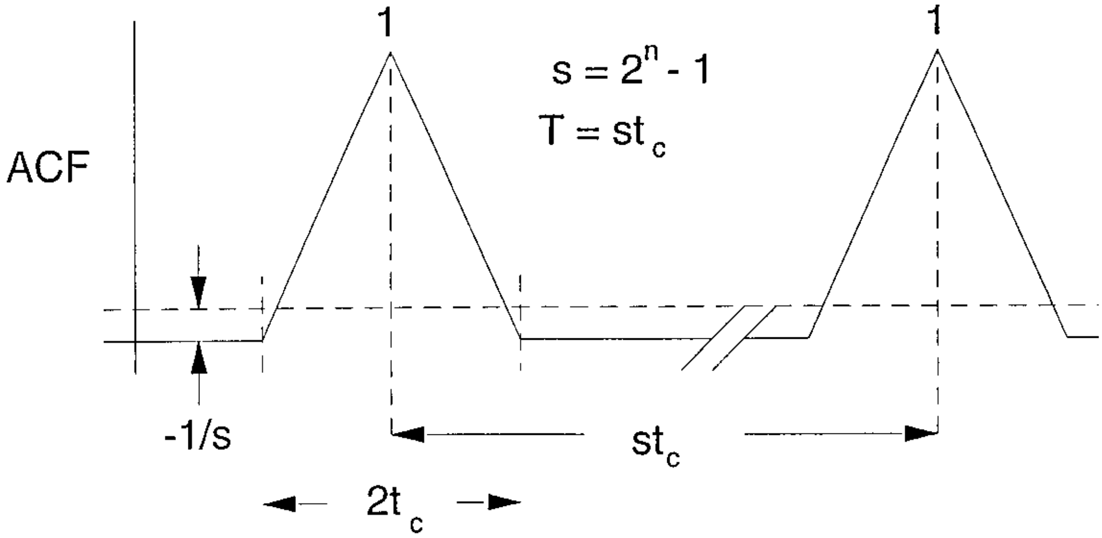


s(t) = d(t) p(t)

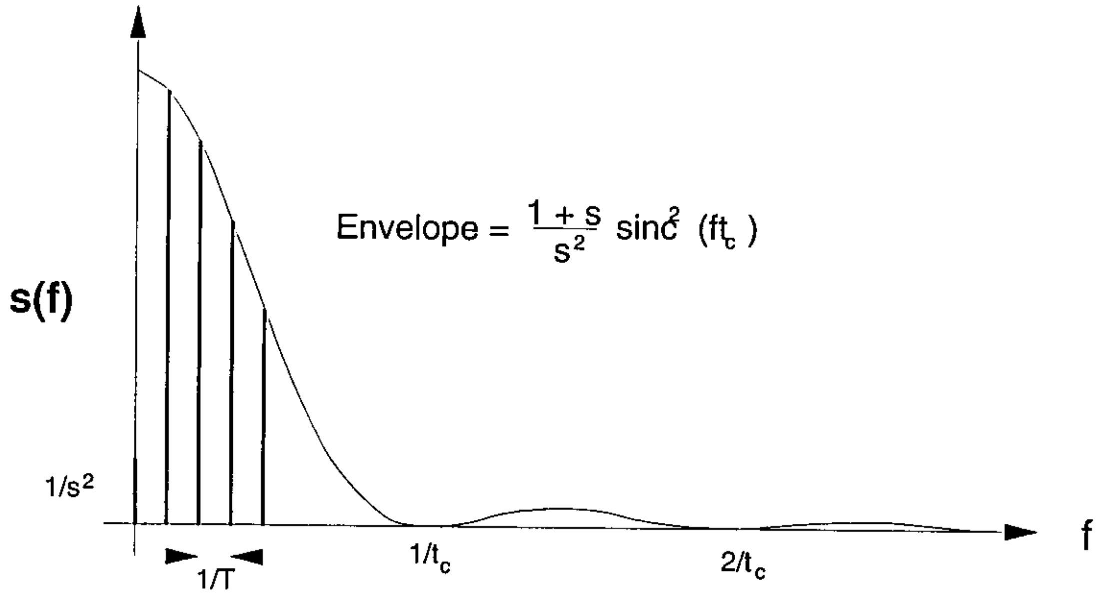
Spreading Code Generation

- Pseudo Random Binary Sequence
  - Maximal Length Shift Register Sequences
  - Primitive Polynomials > Feedback Taps
- Basic Code Properties
  - Good Auto-Correlation Properties
  - Good Run-length Distribution
  - N Registers yield 2^N-1 length sequence

Auto-correlation of m-sequence



Power Spectral Density



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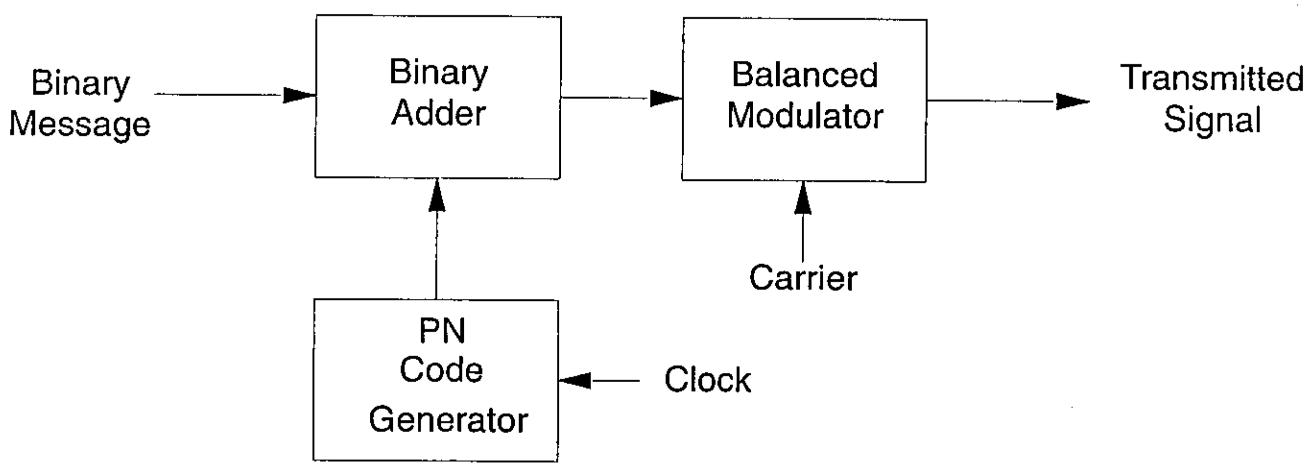
Direct-Sequence Transmitter



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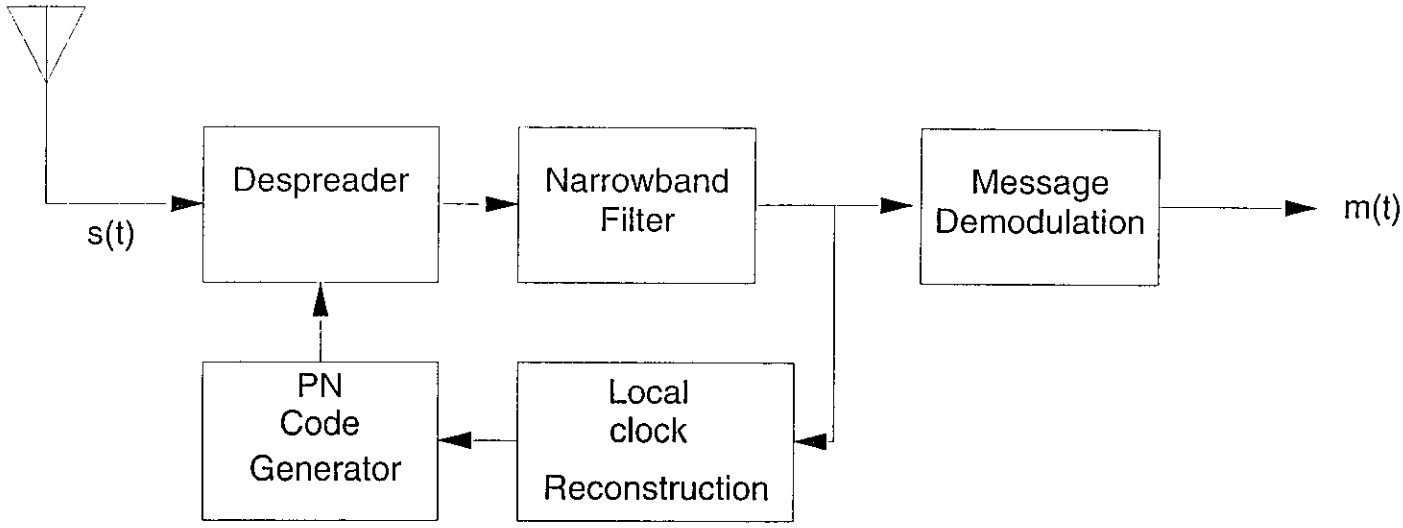
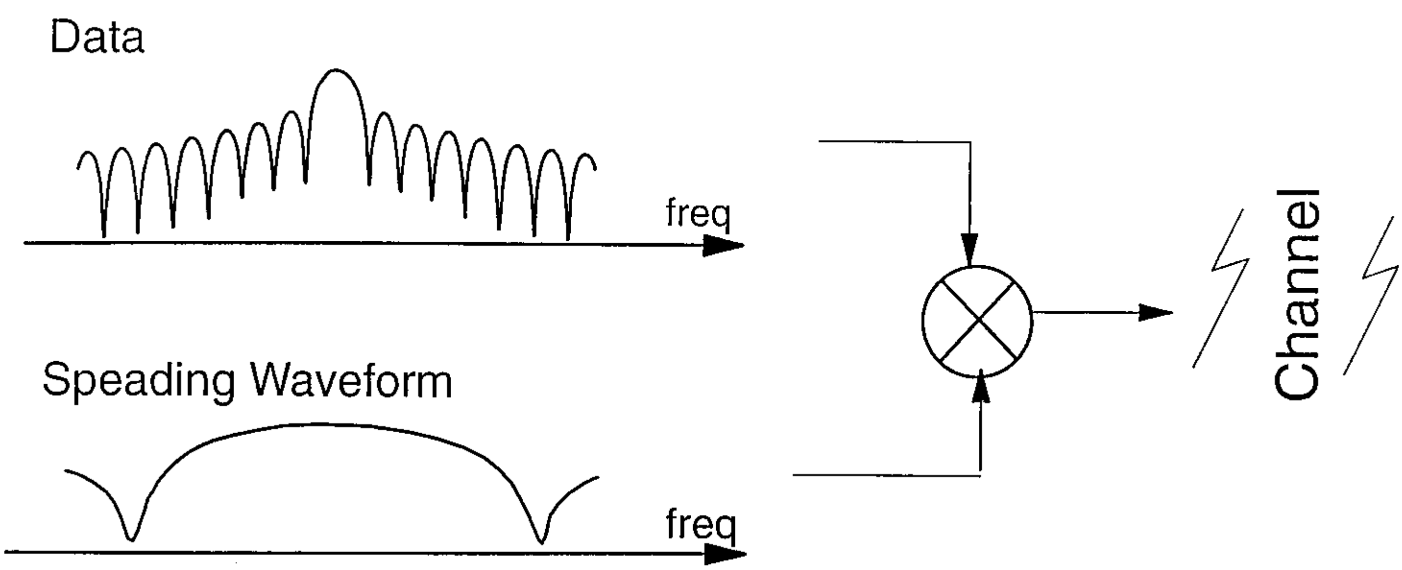
Direct-Sequence Receiver



Processing Gain in DS-SS Systems



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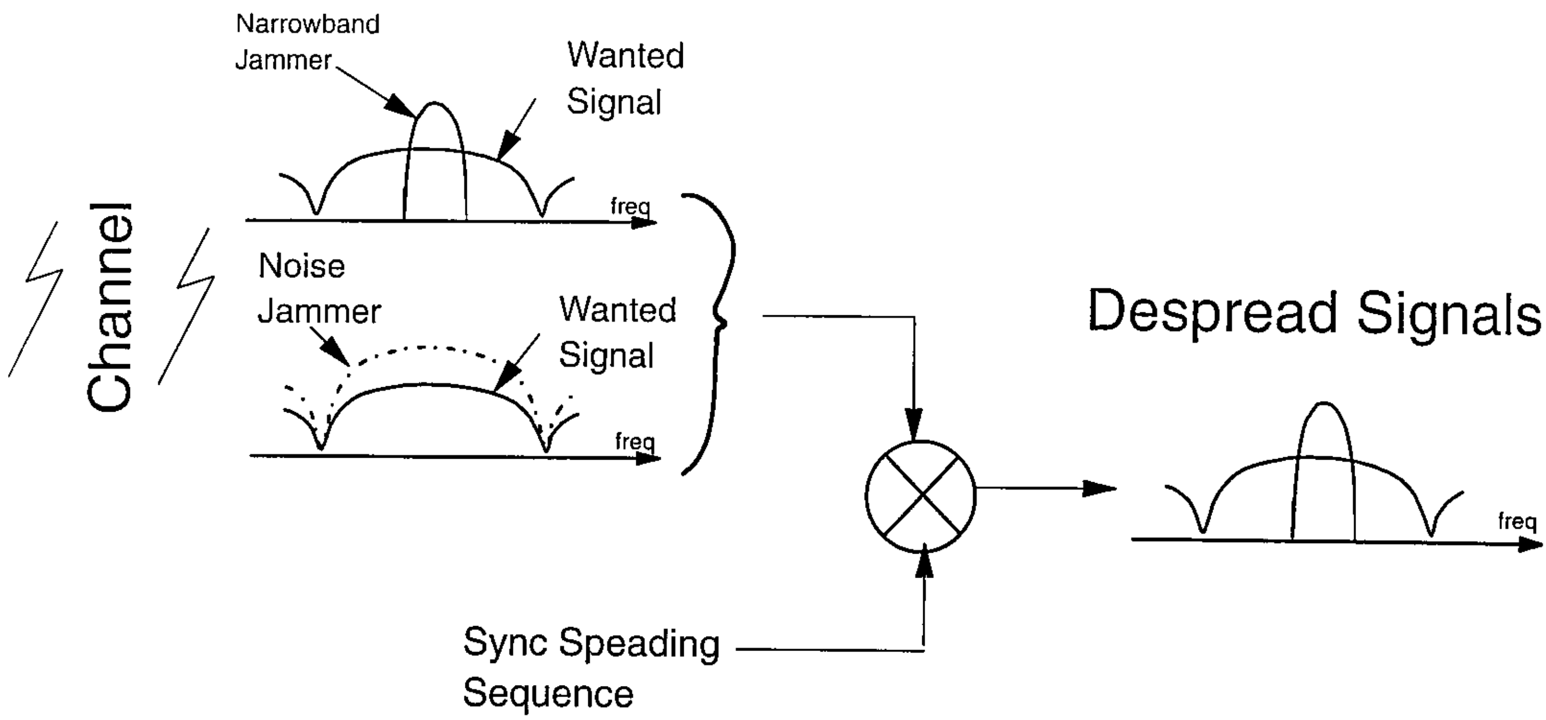
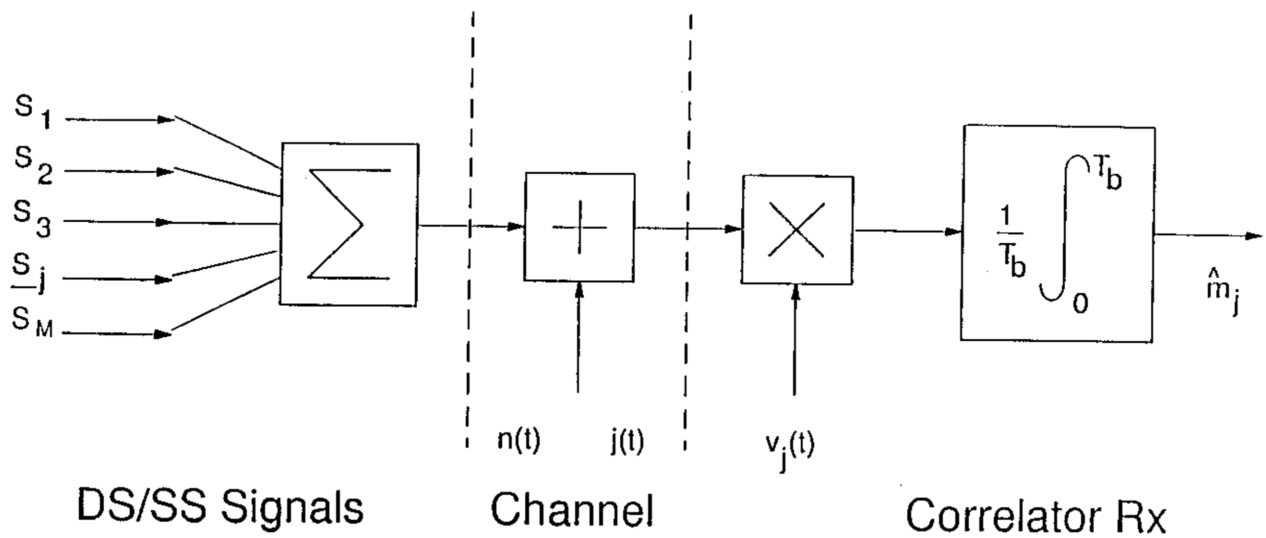
Processing Gain in DS-SS Systems



Multiple Access in the Code Domain

- Multiple m-sequences
  - Poor index of discrimination
- Perferred Pairs of m-sequences, eg: Gold & Kasami
  - Good Auto-Correlation Properties
  - Low Cross-Correlation Properties
  - Code set limited
- Use of long codes
  - Multiple code offsets of master code
  - Requires sync (good for cellular)

Multi_user DS/SS System - CDMA



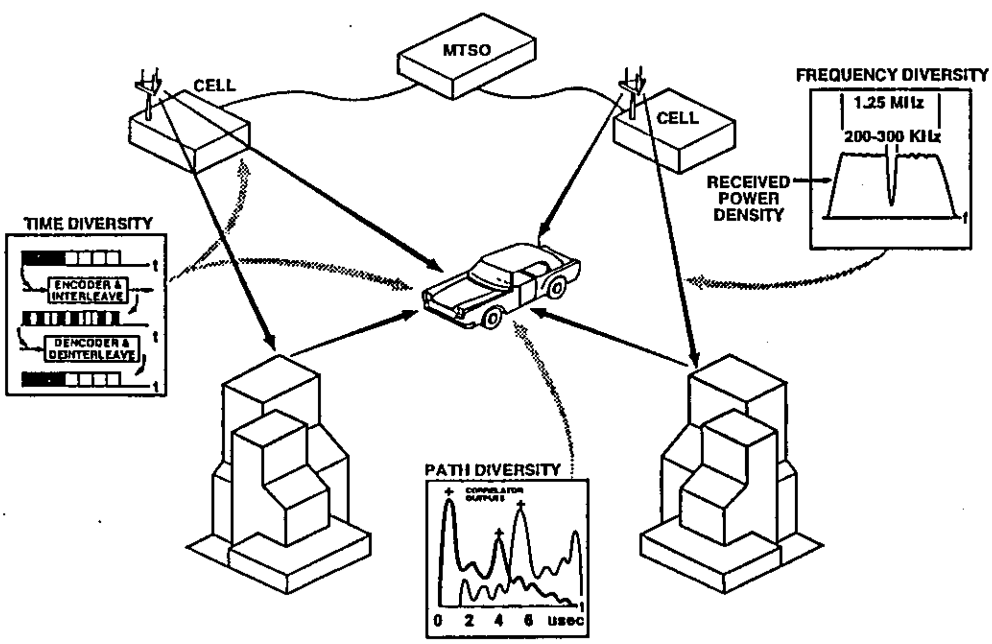
DS-CDMA Capacity Enhancements

- Note Capacity is Self Interference Limited

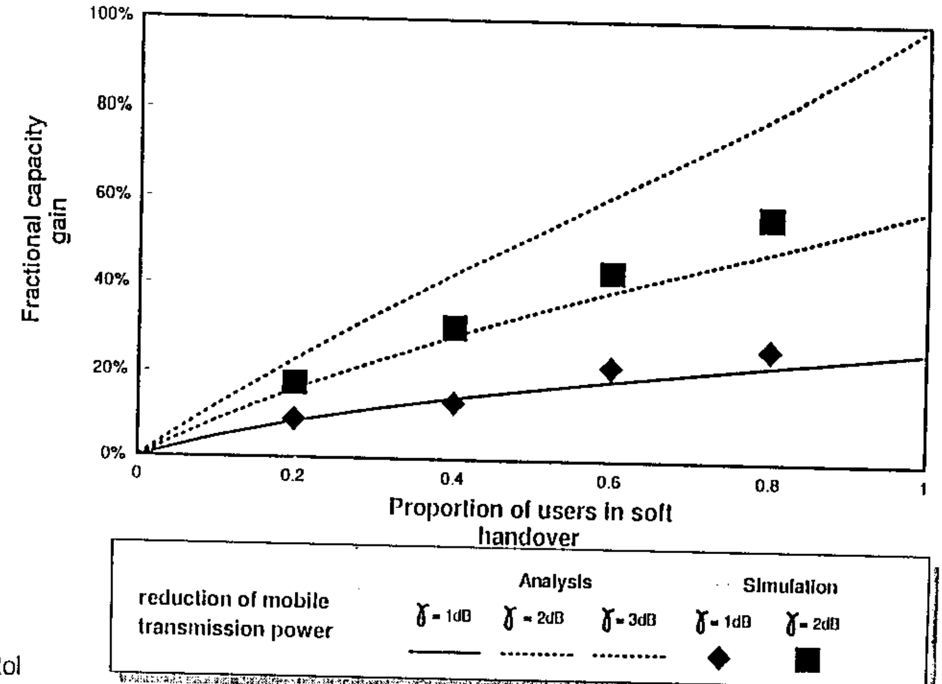
- Enhancement Techniques
  - Voice Activity Detection
  - Sectorised Antennas
  - Diversity Signal Processing
  - Macro-Diversity during handover

- Impact of Cellular Operation
  - Frequency Reuse Efficiency

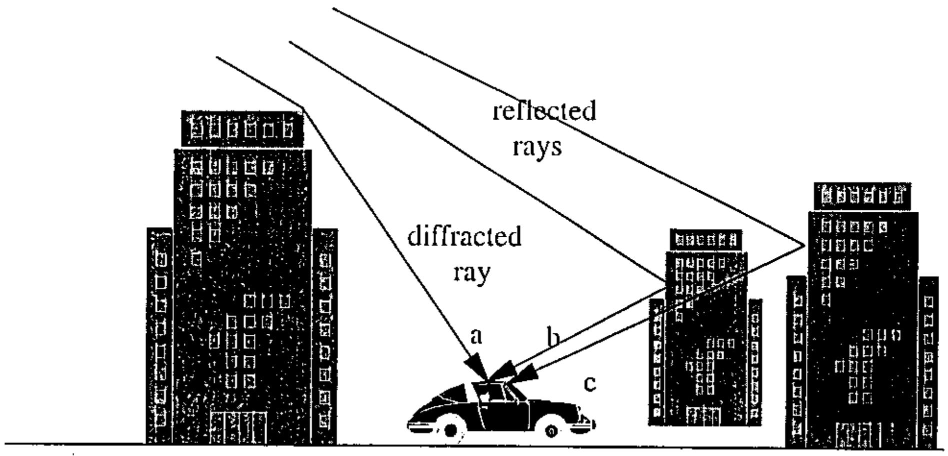
Handover

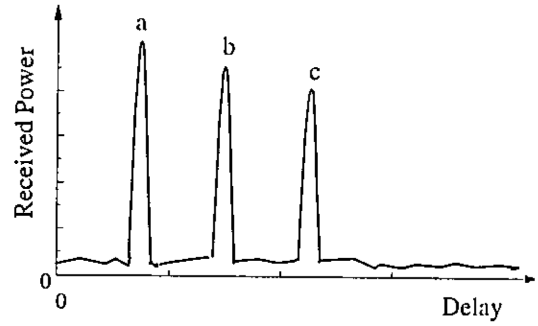


Effect of diversity handover on system capacity



DS-CDMA & the Mobile Channel





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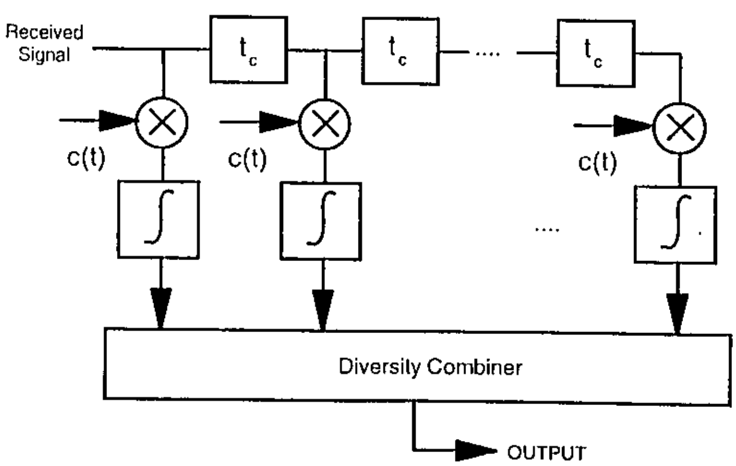
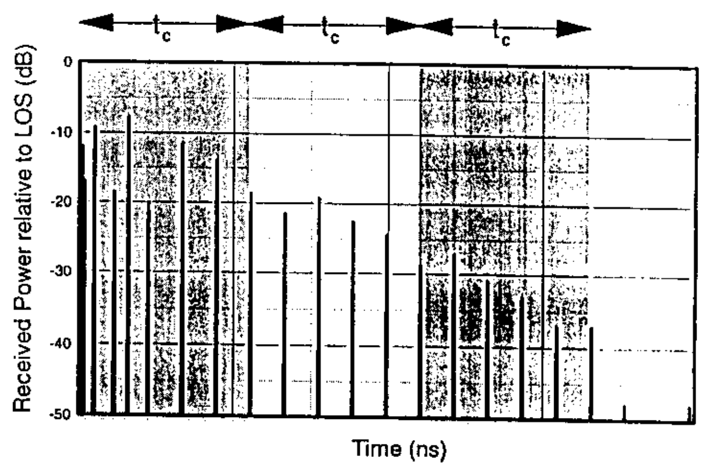
Direct Sequence Rake Reception



(i) Rake Receiver



(ii) Exploitation of Power Delay Profile

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MULTIPATH EXPLOITATION

- **Resolvable Multipath Components**

$$L \leqslant \frac{T_m}{T_c} + 1$$

T_m - Total Multipath Delay Spread

T_c - Spreading Code Chip Duration

- **Path Diversity**

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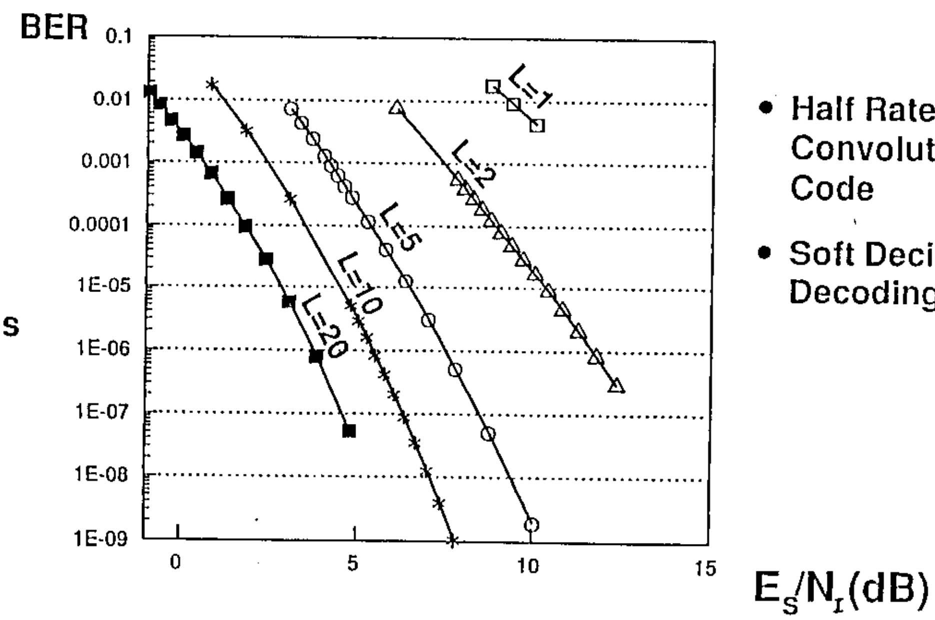
URBAN: BIT ERROR RATE

- Log-normal Rayleigh Channel
- Maximal Ratio Combining, L Diversity Paths



- Half Rate Convolutional Code
- Soft Decision Decoding

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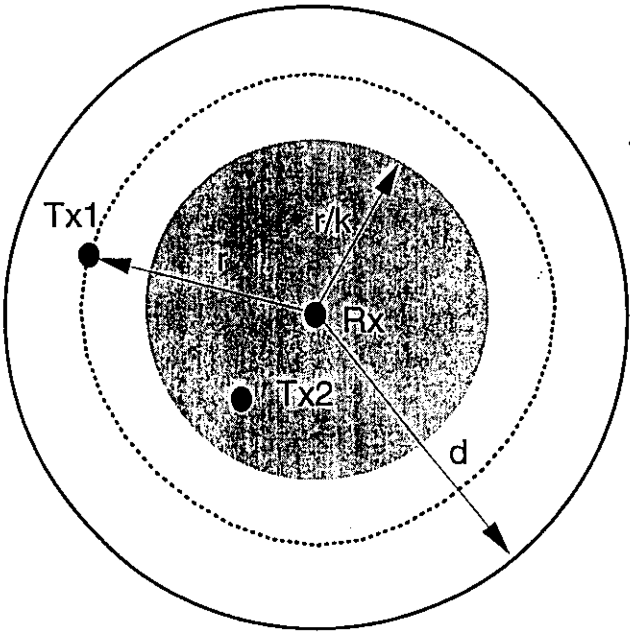
Near-Far Blocking



Tx1: Wanted Transmitter
Tx2: Unwanted Transmitter
Rx: Reference Receiver

Blocking of Tx1 transmission due to high level IMD from Tx2

Near-far Effect

- Signals arriving at BS are at different power levels due to path loss, shadowing and multipath fading.
- This is the near-far problem and requires careful power control to ensure that all signals arrive at the same power level.
- If this is not achieved, the performance will be seriously degraded.
- DS-CDMA schemes generally employ a combination of open and closed loop power control to minimise this effect.
- Near-far resistant techniques can be employed effectively to mitigate this problem.

Direct-Sequence Spread Spectrum (DS/SS)

ADVANTAGES

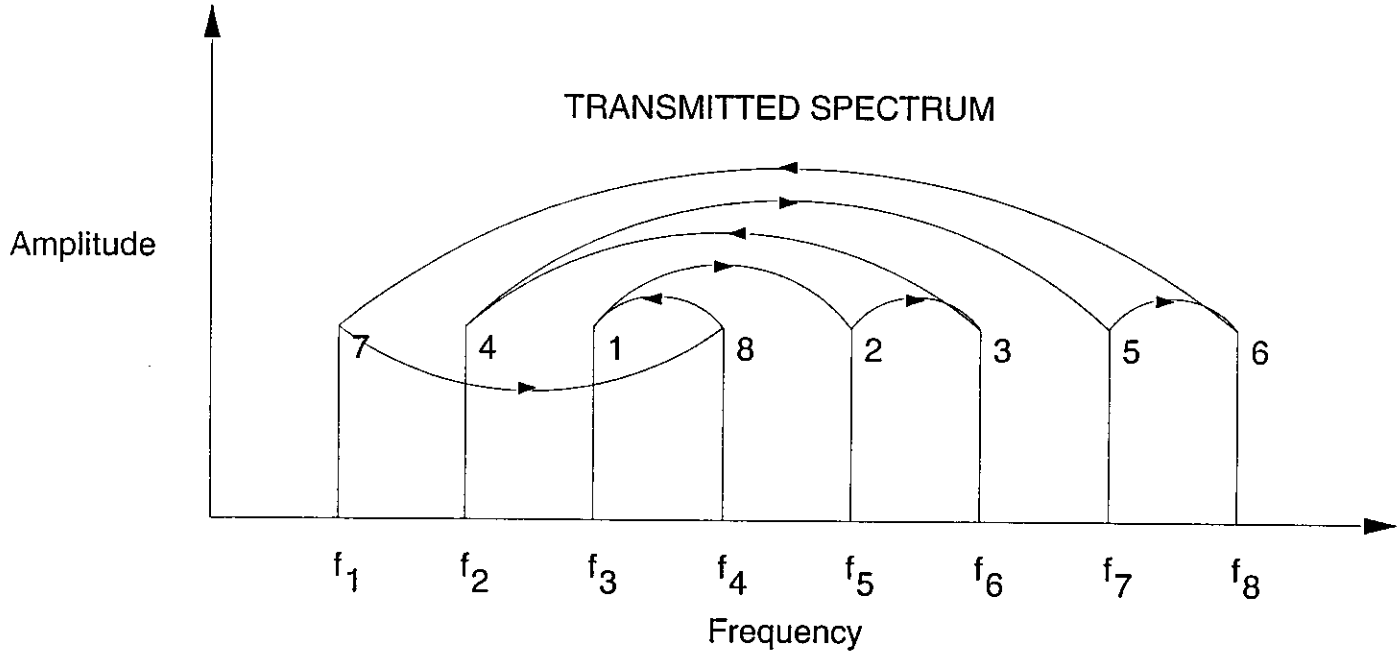
- Easy code generation
- Simple synthesiser - single RF carrier
- Anti-jam margin (20 - 30 dB)
- Selective addressing (CDMA)
- Message privacy / security
- Difficult to intercept (LPI)
- Coherent demodulation possible

Direct-Sequence Spread Spectrum (DS/SS)

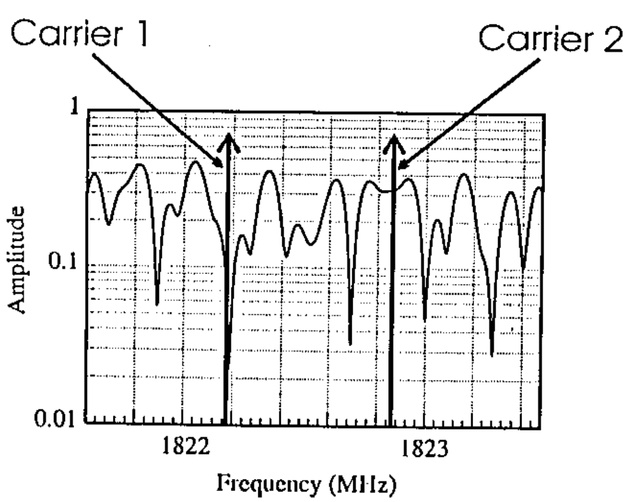
DISADVANTAGES

- Synchronisation difficult
- Poor near-far performance
- Stringent clock stability required
- Continuous bandwidth required
- Spread bandwidth practically limited to 10-20 MHz

Frequency Hopping



The Effects of Frequency Hopping



- inherent *frequency* diversity
- *interference* diversity

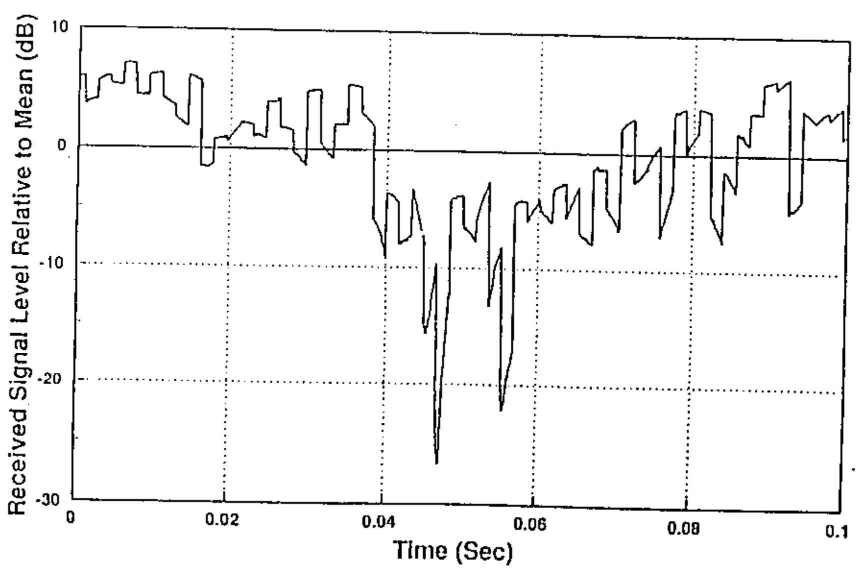
Hop Rates in a FH System

- Fast Frequency Hopping
  - data symbol spread over several hop frequencies
  - *symbol diversity*
  - very resistant to jamming and interference, often used in military systems

- Slow Frequency Hopping
  - several data symbols on each hop frequencies
  - *codeword diversity*
  - less complex hopping synthesiser required

FH Propagation Characteristics

Typical Received Envelope



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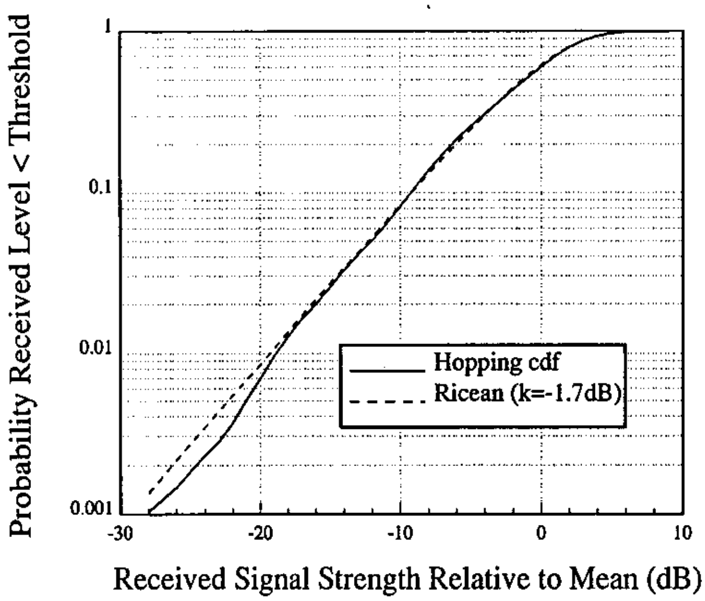
The Frequency Hopped Channel



Hopping cdf with
Rician best-fit curve

- Average channel properties (cdf) *unchanged*
- Improvement in *instantaneous* channel properties

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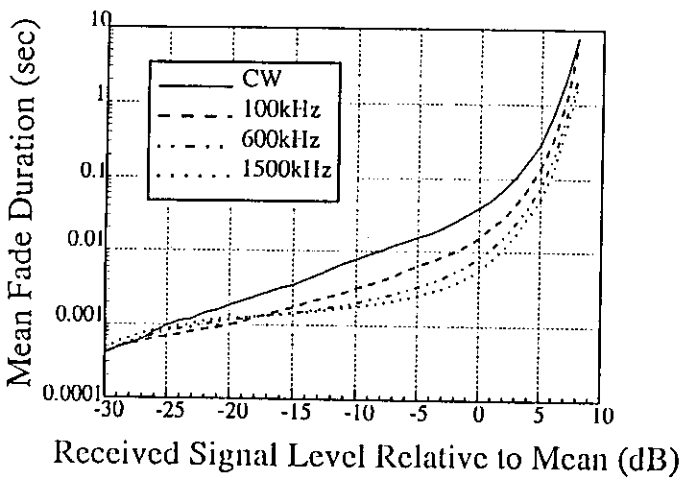
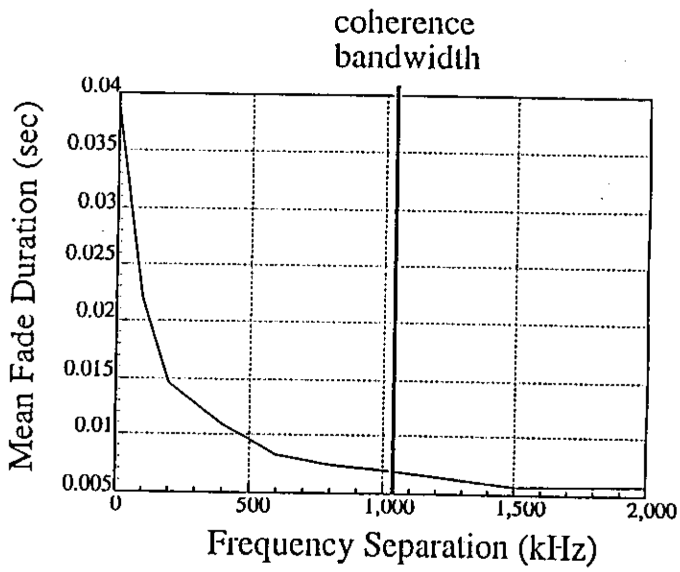
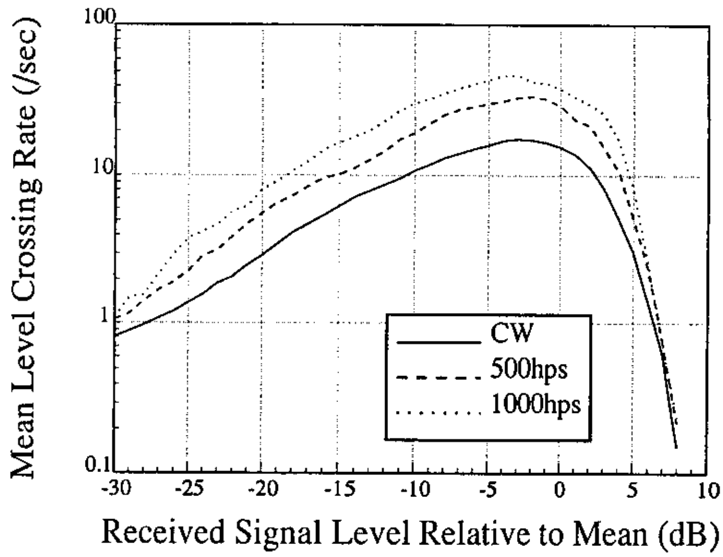
Mean Fade Duration





- Hopping improves the instantaneous channel characteristics
  => reduces burst errors
- Spacing between adjacent hop frames must provide uncorrelated fading
- Diminishing returns for hop bin separation >> coherence bandwidth

Level Crossing Rate



FH Propagation Summary

- Long term, average statistics unchanged
  (such as cumulative distribution)
- Hopping improves instantaneous channel statistics
  (such as level crossing rate and mean fade duration)
- Trade-off between improved performance and hardware complexit
- Diminishing returns for increasing *system bandwidth*

FH Implementation Issues: Services Offered

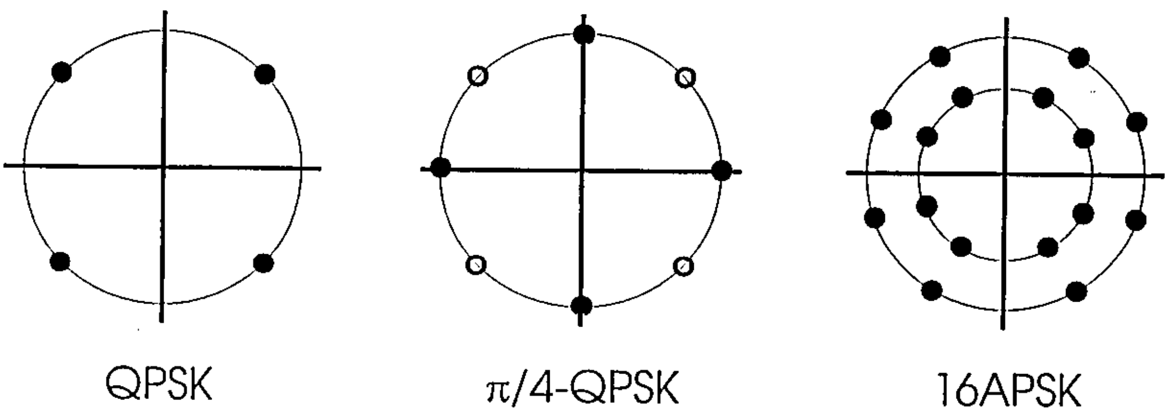
- Required Services (PCS)
  - Voice (8 kbps normal, 64 kbps high quality)
  - Video (64 kbps)
  - Data (up to 2 Mbps)

- Conventional FH is inherently narrowband
  => Data Rate limited by intersymbol interference

- Methods for combating wideband fading in FH
  - Inherent advantage of FH: burst errors randomised
  - Equalisation
  - Frequency Hopped Multi-Carrier

FH Implementation Issues: Modulation Scheme

- Coherent or Differential?
- Traditionally FSK
- Linear Modulation Techniques



Constellation Diagram

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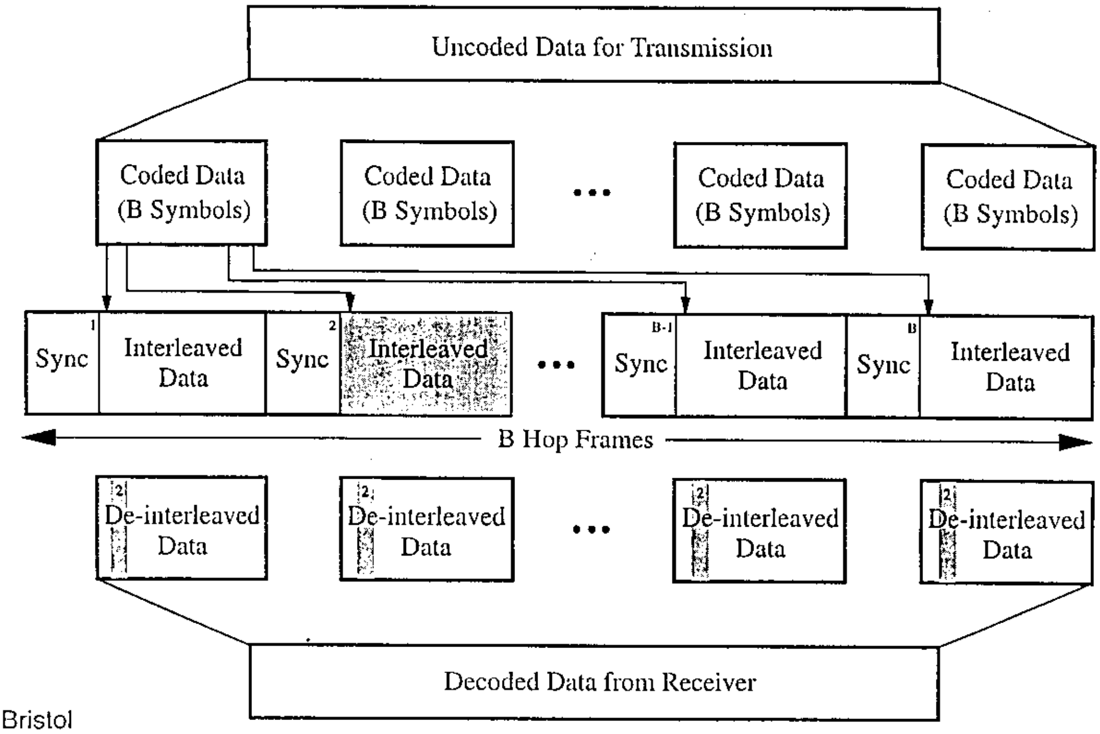
Frequency Hopping - Coding & Interleaving



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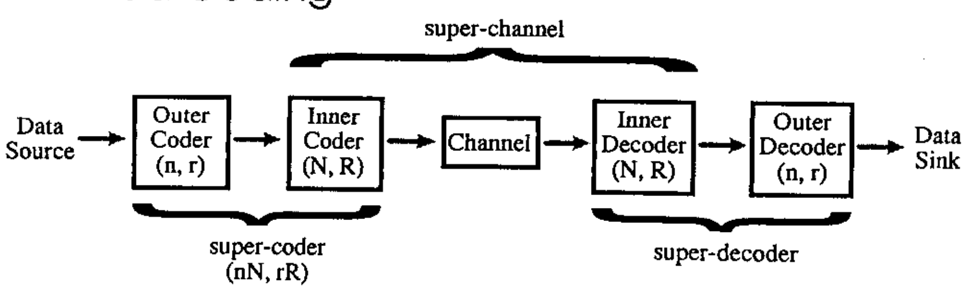
FH Implementation Issues: Coding and Interleaving

- Interleave over many hop frames to randomise burst errors
- Maximum delay for intelligible speech is approx. *40msec*
  => Hop rate must be high enough to provide uncorrelated symbols in a codeword
- Conventional coding (BCH or half-rate convolutional)
- Coded modulation (trellis or block)
  - coding is combined with modulation to improve performance
- Concatenated Coding



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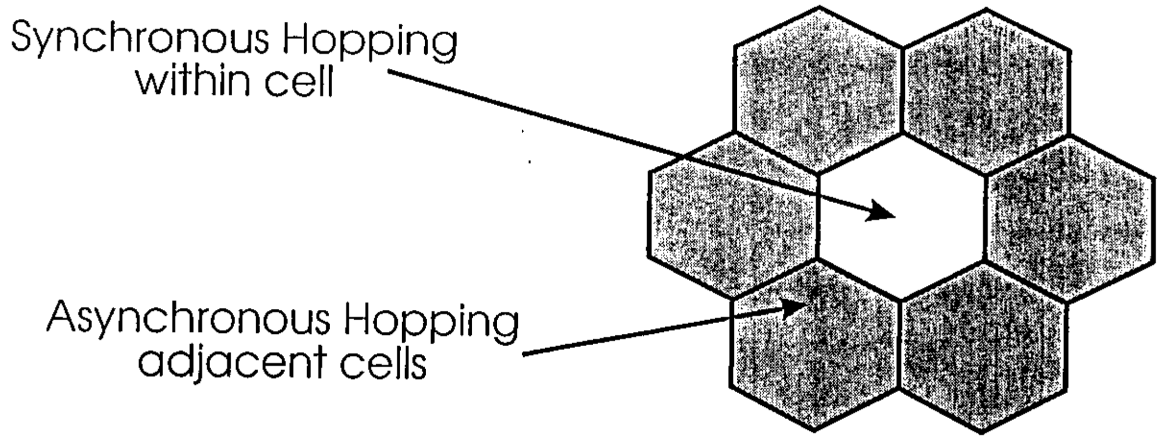
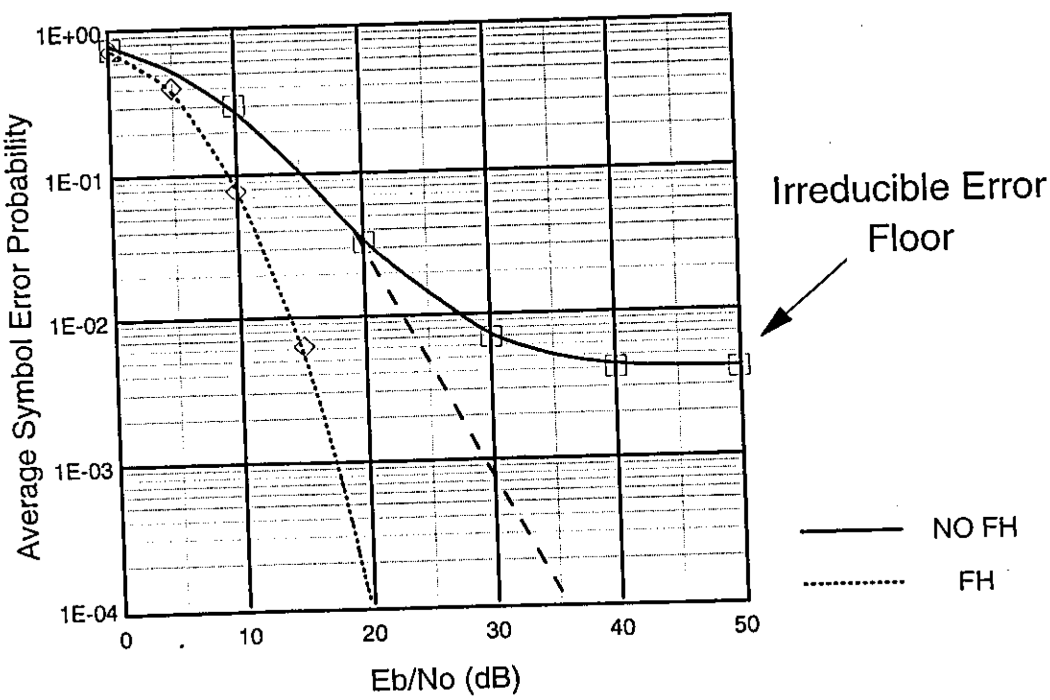
FH Implementation Issues: Multiple Access



- Within cell, each mobile has the same code, with a fixed offset
  => no intra-cell interference
- Adjacent cells use mutually orthogonal hopping codes
  => minimal inter-cell interference
- One-cell repeat pattern

BER - with & without FH



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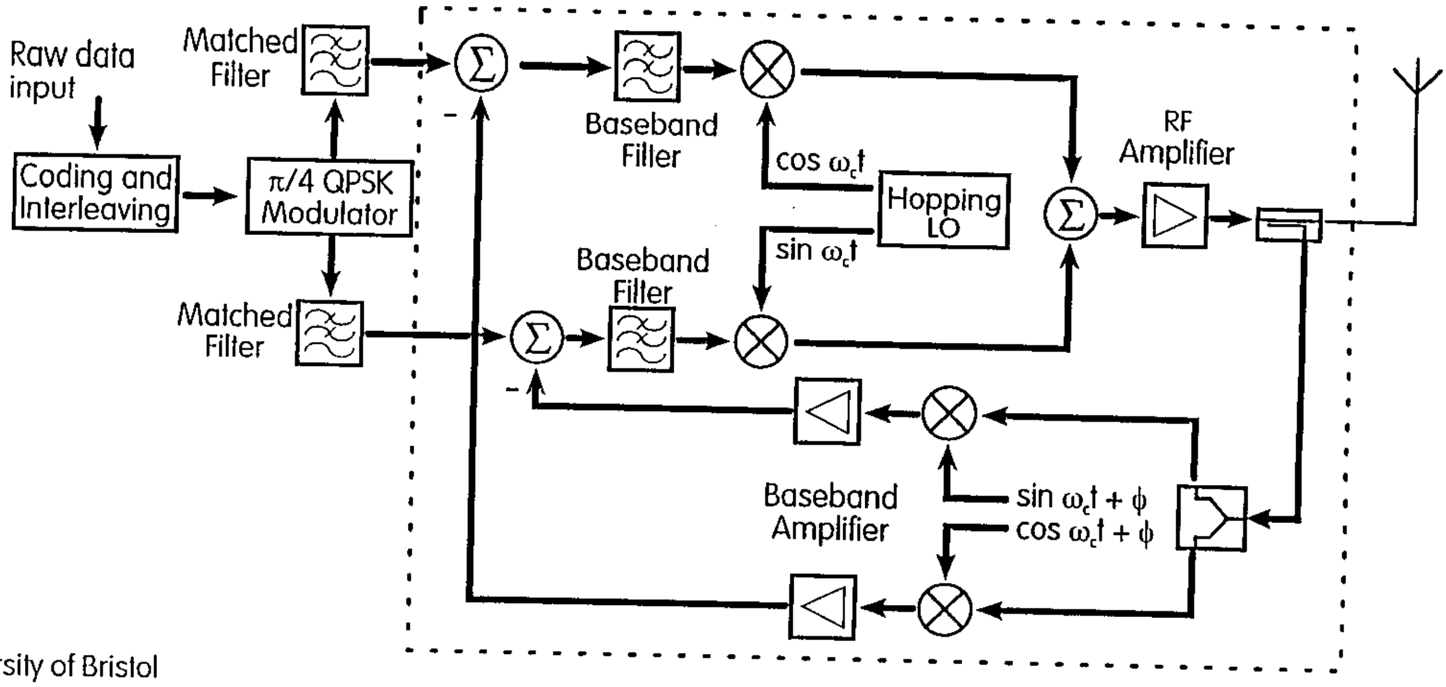
π/4-QPSK Frequency Hopping Transmitter



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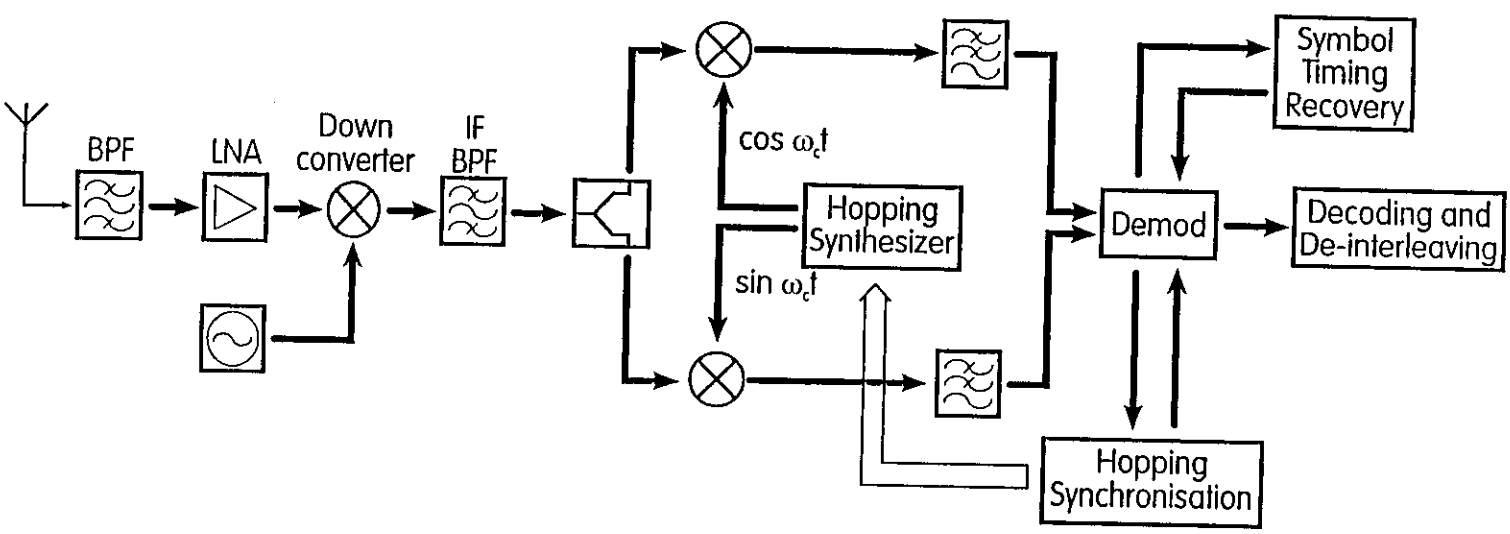
π/4-QPSK Frequency Hopping Receiver



Current FH Systems

System	Hop Rate (hps)	Modulation Scheme	Data Rate	Channel Bandwidth	Capacity
Geotek	150 hps	Coherent $\pi/4$ QPSK	15 kbps using 3 TDM slots 5 kbps vocoder	25 kHz	160
Motorola	500 hps	Coherent QPSK	500 kbps using 10 TDM slots 32 kbps vocoder	400 kHz	20
CCR	500 hps	$\pi/4$ DQPSK	20 kbps using 8 kbps vocoder	16 kHz	21

- All systems employ half-rate convolutional coding, with interleaving < 40 *msec*

Frequency Hopping CDMA in PCS

ADVANTAGES

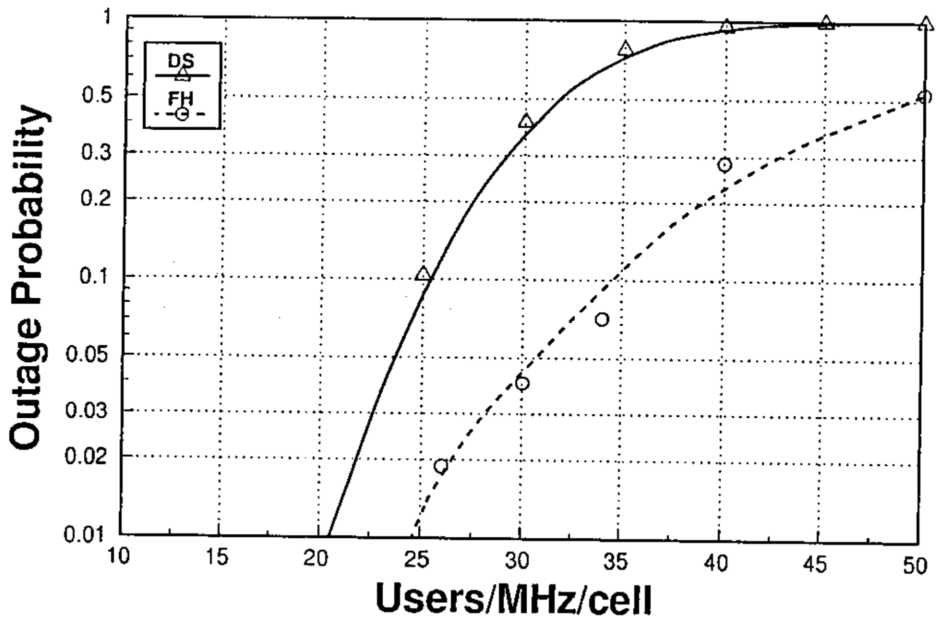
- ☑ Frequency diversity randomizes channel
  => improved instantaneous characteristics
- ☑ Interference diversity and easy synchronisation
  => robust air interface technique
- ☑ Co-existence with non-hopping radio
  (non-contiguous spectrum can be employed)
- ☑ Narrowband technology
  => lower hardware complexity
- ☑ Good near-far performance

Frequency Hopping CDMA in PCS

DISADVANTAGES

- ☒ Sophisticated hopping synthesiser required
- ☒ Spectral containment requires controlled turn-on/off
- ☒ Coherent demodulation difficult
- ☒ Possible data rate limitations

Capacity Comparison



Overall Comparison

- **Capacity**
  - Possible advantage with DS due to ability to support mixed services.
- **Hardware**
  - Cost, size and power consumption evenly matched.
- **Flexibility**
  - Support of mixed cells and multiple operators possible advantage of FH (near-far resistant).
- **QoS**
  - Soft handover advantage of DS.
  - EMC is a possible problem with slow FH?