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

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Mobile and Personal Communications

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Mobile and Personal Communications

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"Mobile and Personal Communications" Outline of Lectures

- Personal communication system requirements
- Multiple Access Techniques
  - Frequency Division Multiple Access
  - Time Division Multiple Access
  - Code Division Multiple Access
- Aspects of Network Planning
- Techniques to improve performance
  - Diversity and Diversity Combining
  - Equalisation

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Personal Communication Systems and Requirements

- Next generation of mobile communications:
  - Personal Communication System (PCS)
    - also known as Personal Communication Networks (PCN)
  - Universal Mobile Telecommunications System (UMTS)
  - International Mobile Telecommunications (IMT-2000)
    - formerly Future Public Land Mobile Telecommunications System (FPLMTS)
  - *Third Generation*
- Requirements:
  - high capacity
  - low cost
  - high quality
  - wide range of services

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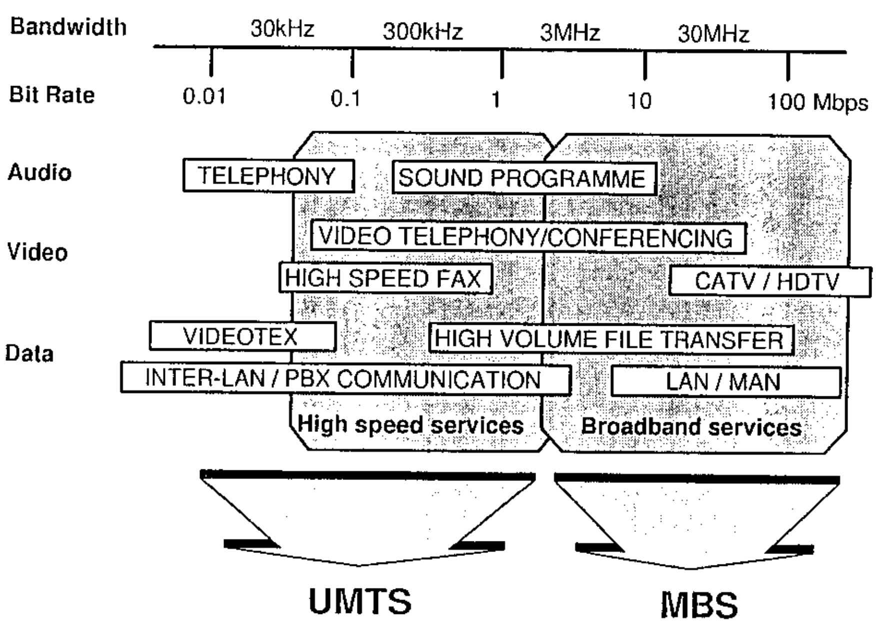
IBC Bit Rate Requirements



Source: IBC Common Functional Spec. D730

Multiple Access Requirements

A cellular system employs a *multiple access technique* to control the allocation of the network resources. The purposes of a multiple access technique are:

- To provide each user with unique access to the shared resource: the *spectrum.*
- To minimise the impact of other users acting as interferers.
- To provide efficient use of the spectrum available.
- To support flexible allocation of resources (for a variety of services).

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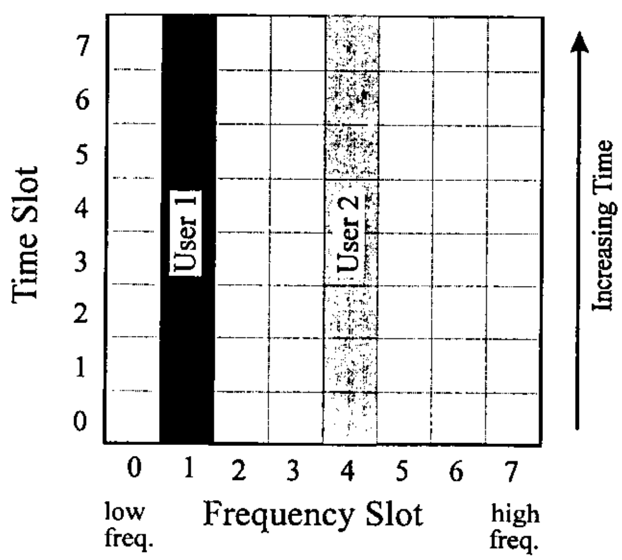
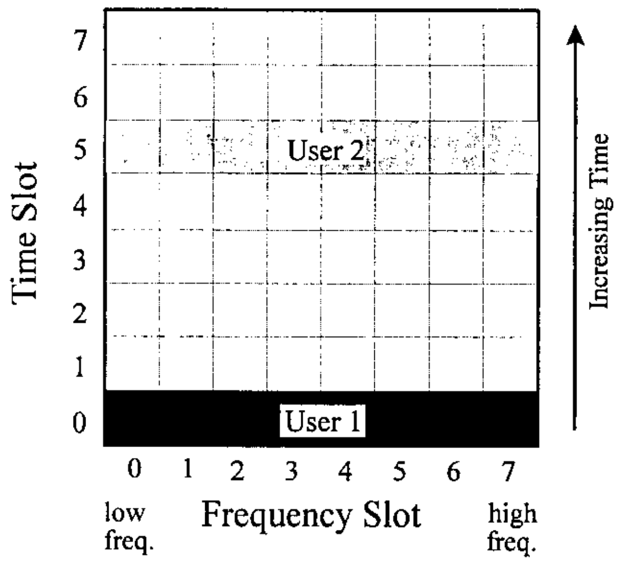
Frequency Division Multiple Access (FDMA)



2 users shown

- Each user is assigned a unique frequency for the duration of their call.
- Severe fading and interference can cause errors.
- Complex frequency planning required. Not flexible.
- Used in analogue systems, such as TACS (Europe), and AMPS (USA).

Time Division Multiple Access (TDMA)



2 users shown

- Each user can use *all* available frequencies, for a limited period. The user must not transmit until its next turn.
- High bit rates required, therefore possible problems with intersymbol-interference.
- Flexible allocation of resources (multiple time slots).
- Used in second generation digital networks, such as GSM (Europe), and D-AMPS (USA).

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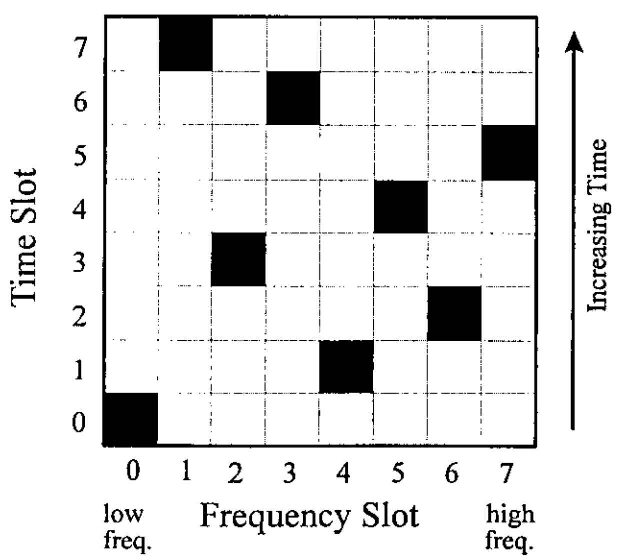
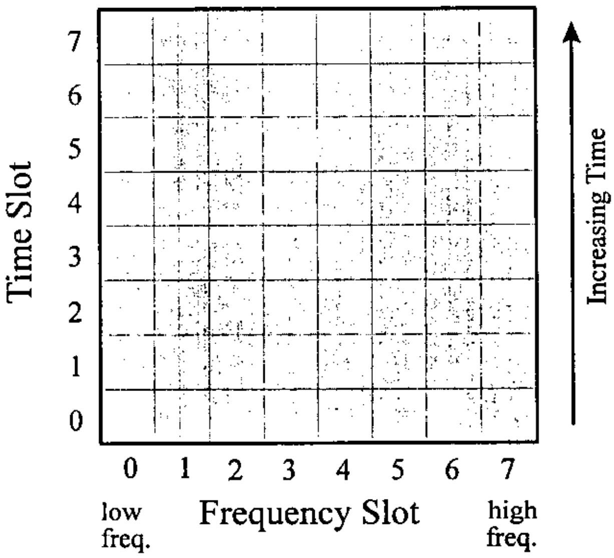
Frequency Hopping Code Division Multiple Access (FH-CDMA)



only 1 user shown

- Each user regularly *hops* frequency over the available spectrum.
- Users are distinguished from each other by a unique hopping pattern (or *code*).
- Interference is randomised.
- Frequency hopping can be implemented as part of GSM. Wireless Local Area Networks can use FH-CDMA.

Direct Sequence Code Division Multiple Access (DS-CDMA)



only 1 user shown

- All users occupy the *same spectrum* at the *same time*.
- The modulated signal is *spread* to a much larger bandwidth than that required by multiplying with a *spreading code.* Users are distinguished from each other by a unique spreading code.
- Very flexible, but complex.
- Currently used in IS-95 (Qualcomm, USA). Wireless Local Area Networks can use DS-CDMA.

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Summary of Multiple Access Techniques: The Cocktail Party

To illustrate the nature of the multiple access techniques, consider a number of guests at a cocktail party. The aim is for all the guests to hold an intelligible conversation. In this case the resource available is the house itself.

- FDMA: each guest has a seperate room to talk to their partner.
- TDMA: everyone is in the same room, and has a limited time to hold their conversation (so they must talk very quickly).
- FH-CDMA: the guests run from room to room to talk.
- DS-CDMA: everyone is in the same room, talking at the same time, but each pair talks *in a different language.*

Duplex Communication

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- Two way communication is called *duplex* (eg. for cellular radio). One way is called *simplex* (eg. for paging).
- The link from the base-station to mobile is the *down-link*. The link from the mobile to base-station is the *up-link*.
- The up-link and down-link can exist simultaneously on different frequencies: *Frequency Division Duplex* (FDD).
- The up-link and down-link can exist on the same frequency at different times: *Time Division Duplex* (TDD).

Traditional Cellular Design

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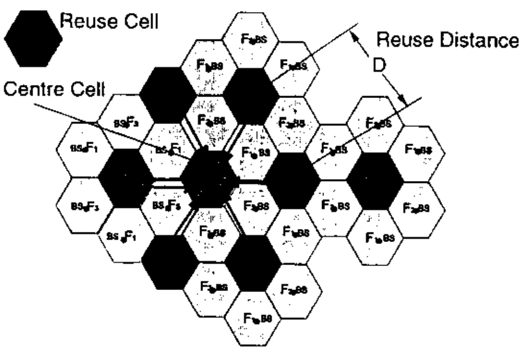


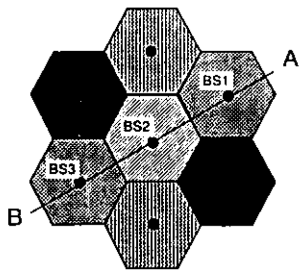
- Continuous coverage.
- Adjacent cells cannot use the same frequency, as users would interfer with each other (compare to CDMA).
- Dark cells have the same frequency.
- This network has a *reuse pattern* (or *cluster size*) of three, ie. three different frequency bands are used.

D is the *reuse distance* between cells on the same frequency (*co-channel cells*). Cell radius is *R*. This can be related to the reuse distance by:

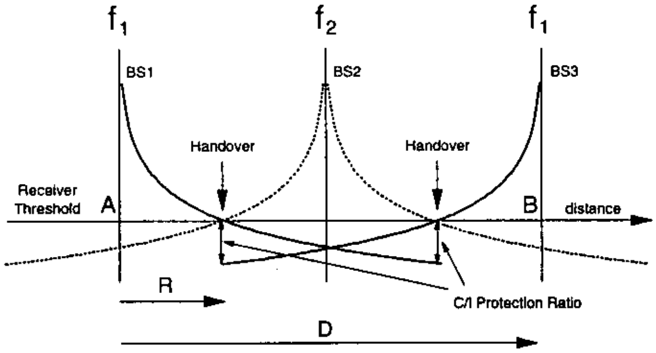
$$D/R = (3N)^{0.5}$$

where N is the cluster size

Frequency Reuse and Cellular Handover



(i) 4 frequency re-use pattern



(ii) Power and frequency vs distance

- As the user moves between cells on different frequencies it is necessary to *handover* from one cell to another.
- Handover generally occurs when the adjacent basestation power becomes stronger than the current basestation.
- Problems of unnecessary handover (*ping-pong*).

Cellular Capacity Evaluation

- Network capacity is generally defined as the number of channels per MHz per kilometre squared.
- An *Erlang* is represents a single continuous call. A single user is often assumed to represent 0.02 Erlangs (uses the phone for 2% of the time).
- The general equation for capacity is given by

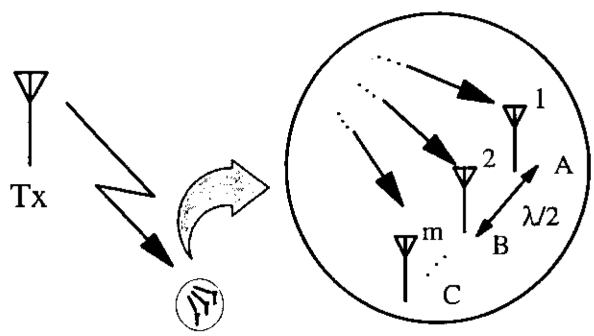
$$\text{Capacity} = \frac{\text{Total Number of Channels}}{\text{Cluster size * Cell area * Total bandwidth}}$$

(in Erlangs/MHz/km^2)

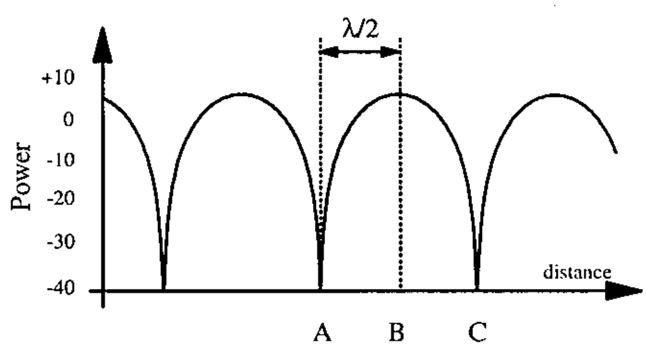
Diversity

- Diversity: the provision of two or more *uncorrelated* (or *independent*) fading paths between transmitter and receiver.
- The uncorrelated fading statistics are combined or selected in some form.
- Performance improvement results as it is unlikely that all the diversity paths will be poor at the same time. Consequently, the probability of *outage* is reduced.
- Methods for generating uncorrelated paths for diversity combining include time, frequency, polarisation, angle, and space diversity.

Space Diversity



(i) Space Diversity



(ii) Power Variation with Distance

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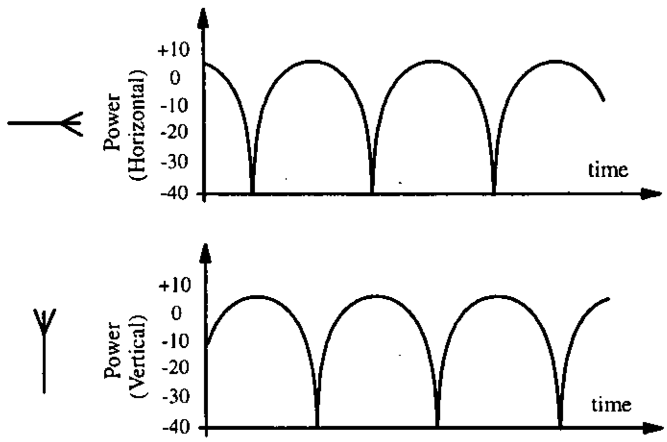
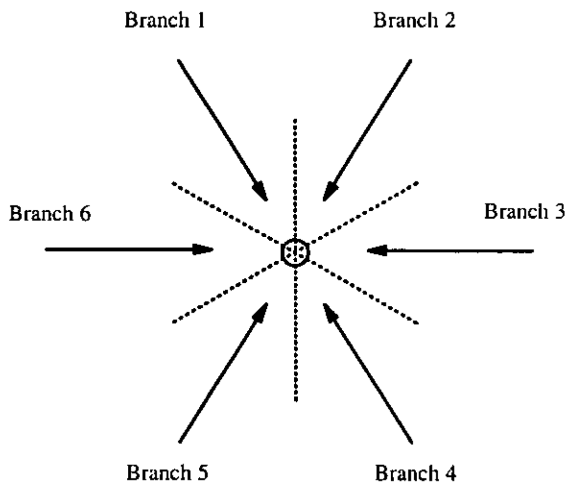
Polarisation and Angle Diversity



(i) Polarisation Diversity



(ii) Angle (Pattern) Diversity

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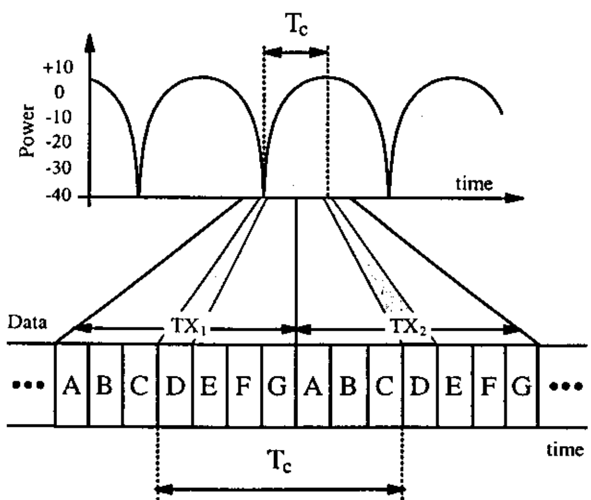
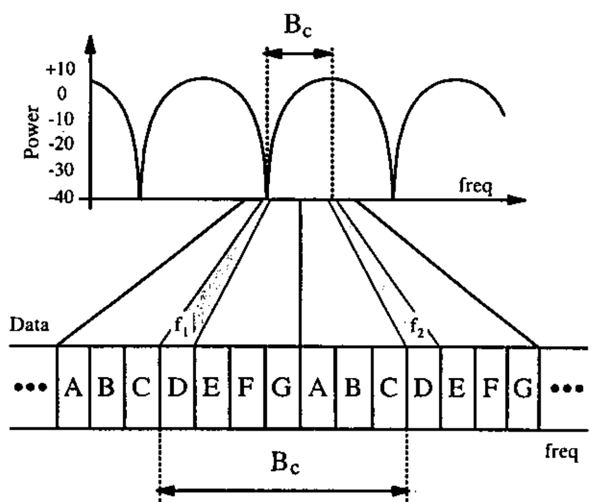
Time and Frequency Diversity



(i) Time Diversity



(ii) Frequency Diversity

- Less desirable: extra signal bandwidth is required

Diversity Combining: Switched (or Scanning) Combining

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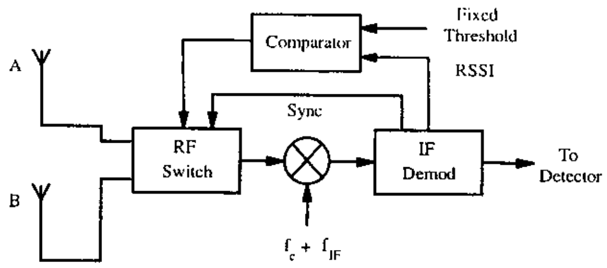
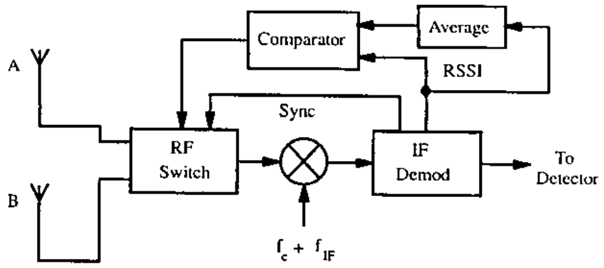


(i) Switch Diversity with Fixed Threshold



(ii) Switch Diversity with Adaptive Threshold

- The current branch remains selected until a metric fails a certain threshold, usually the *Received Signal Strength Indicator* (RSSI). The next branch is then blindly selected.
- An adaptive threshold removes unnecessary switching. When the signal fades relative to the mean, switching occurs.
- This system is cheap and simple, but not ideal.

Diversity Combining: Selection Combining

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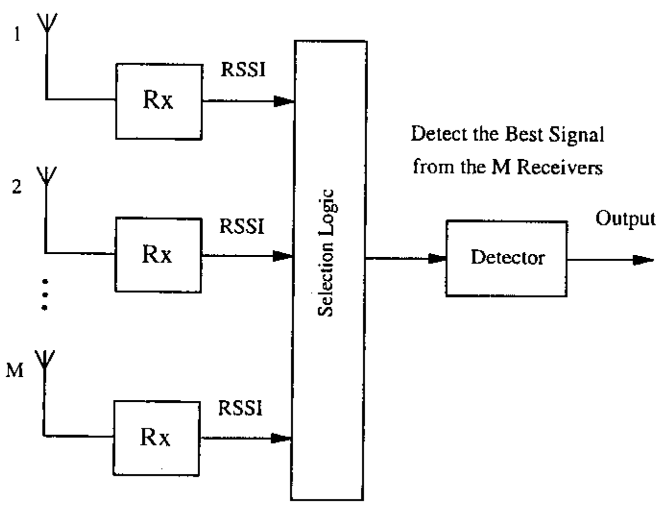
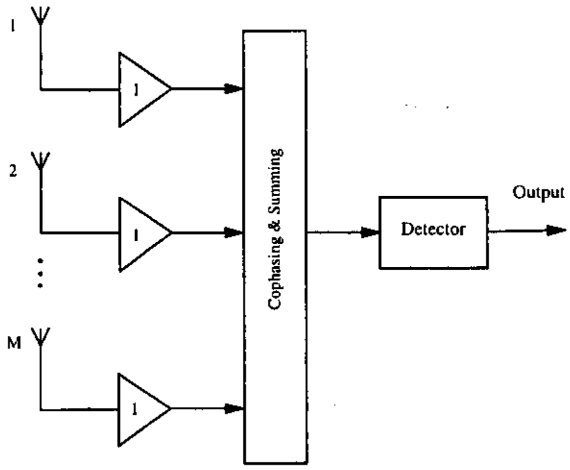


- The most appropriate branch is always selected. Slight performance advantage over switch diversity.
- The system is expensive, as all branchs have to be analysed.
- Using RSSI as a indication of quality is non-ideal, since it is unduly affected by interference.

Diversity Combining: Equal Gain Combining (EGC)



- *Post-detection* combining.
- All branchs are merely cophased and summed.

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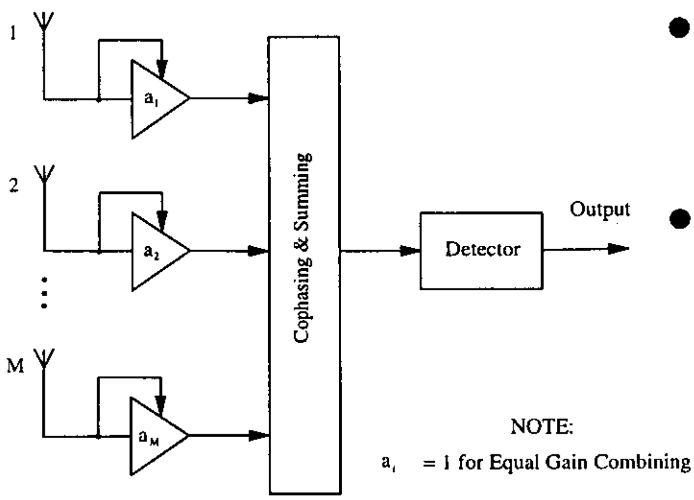
Diversity Combining: Maximal Ratio Combining (MRC)



- Each branch is weighted before summation in proportion to its own *signal-to-noise* ratio.
- Slightly better performance than EGC, but requires the complexity of estimating signal-to-noise ratio.

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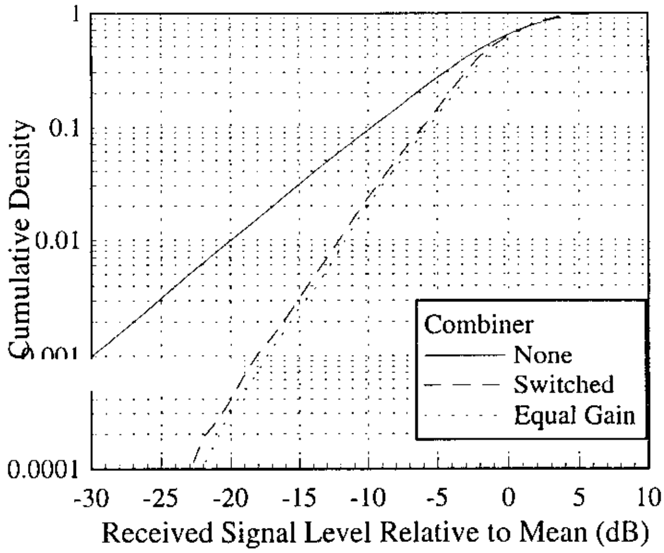
The Effect of Diversity on Fading Statistics



- The fading statistics are improved with the applications of diversity.
- The BER in a Rayleigh fading channel can be significantly reduced with the use of diversity.
- Diversity can offer an 8-12 dB gain in Rayleigh channels. It can also increase the maximum bit rate in a dispersion limited environment by a factor of two.

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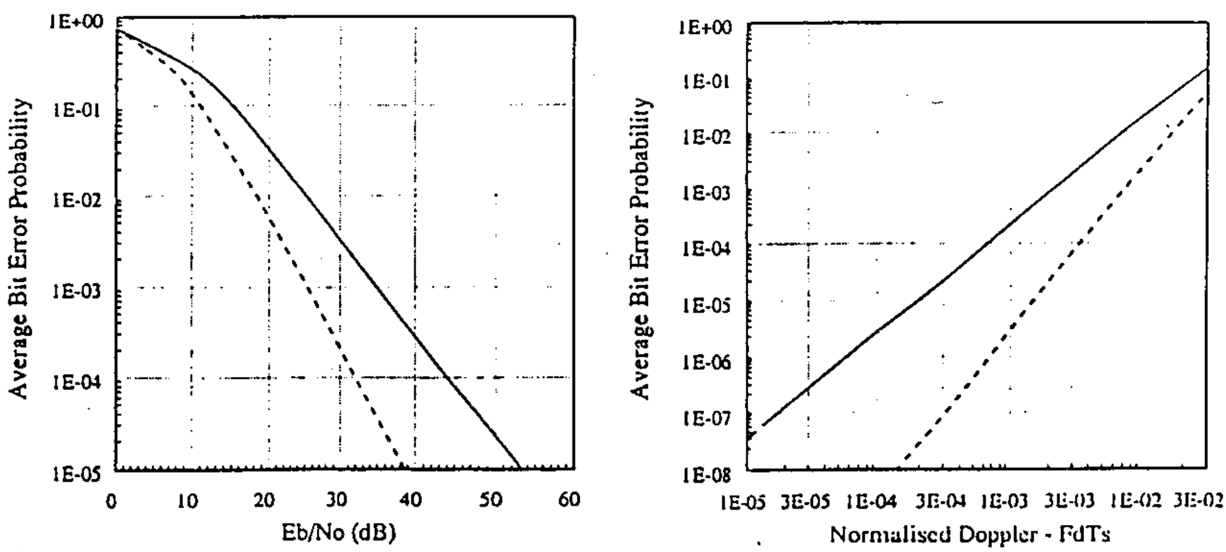
BER IMPROVEMENT WITH DIVERSITY



No Diversity ---------- 2 Branch Diversity

The effects of Equalisation

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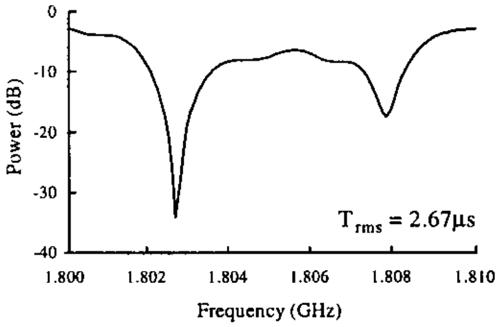
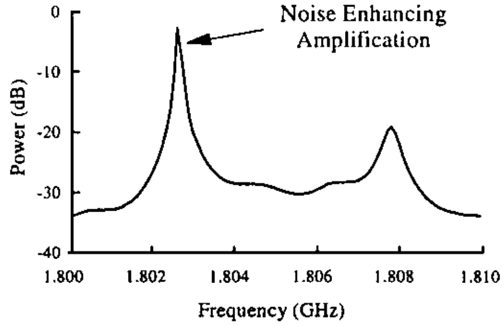


(i) Channel (Frequency Domain)



(ii) Forward Filter (Frequency Domain)

- *Frequency-selective fading* arises due to time-dispersion in the multipath channel. This type of *wideband* fading causes *irreducible* errors, unless its effects are mitigated.
- Equalisation is employed to remove the harmful frequency-selective fading. It acts as an adaptive filter, to produce an output signal with a flat frequency response. Consequently, error-free transmission at high data rates is possible.

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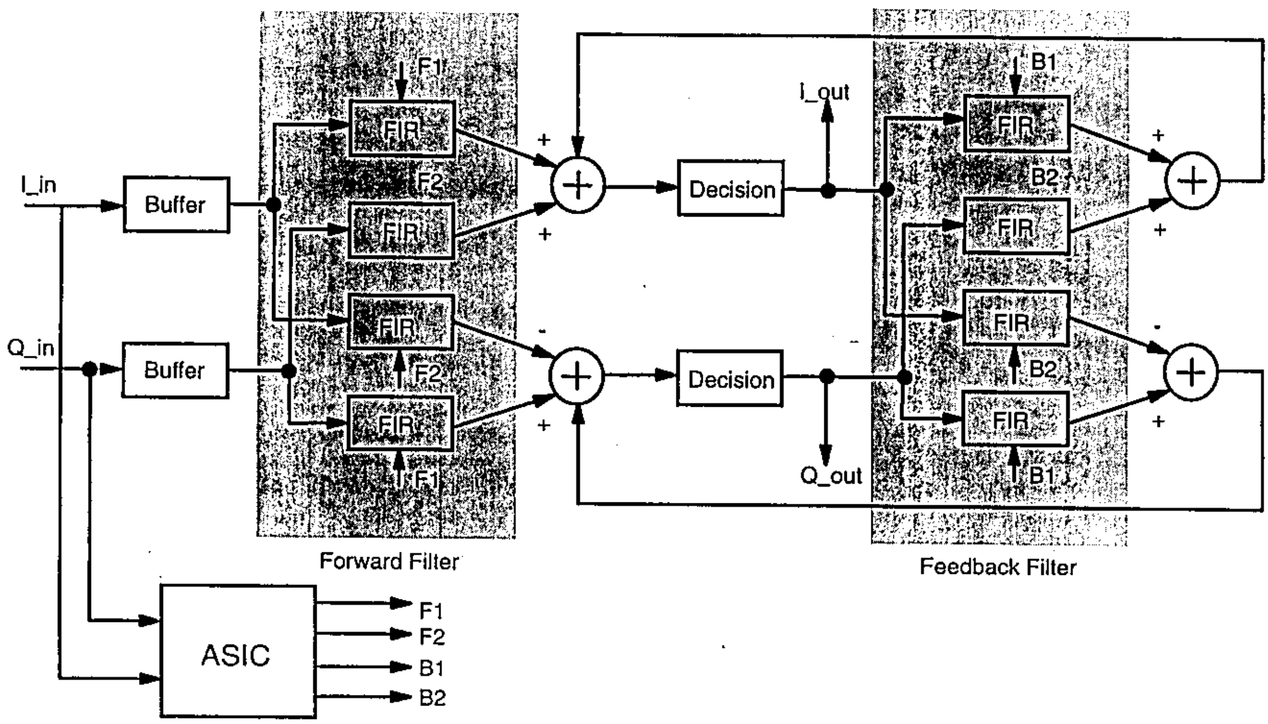
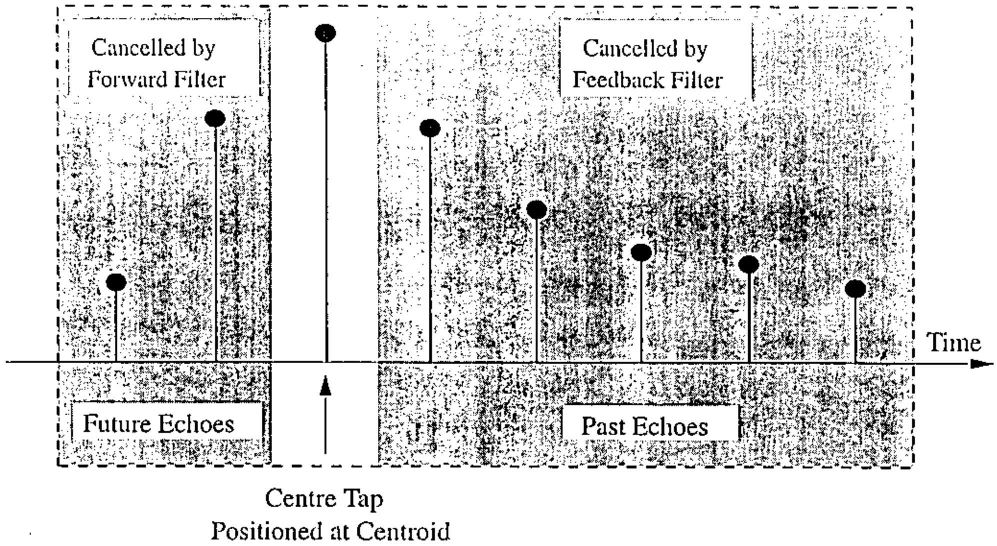
Equaliser Implementation

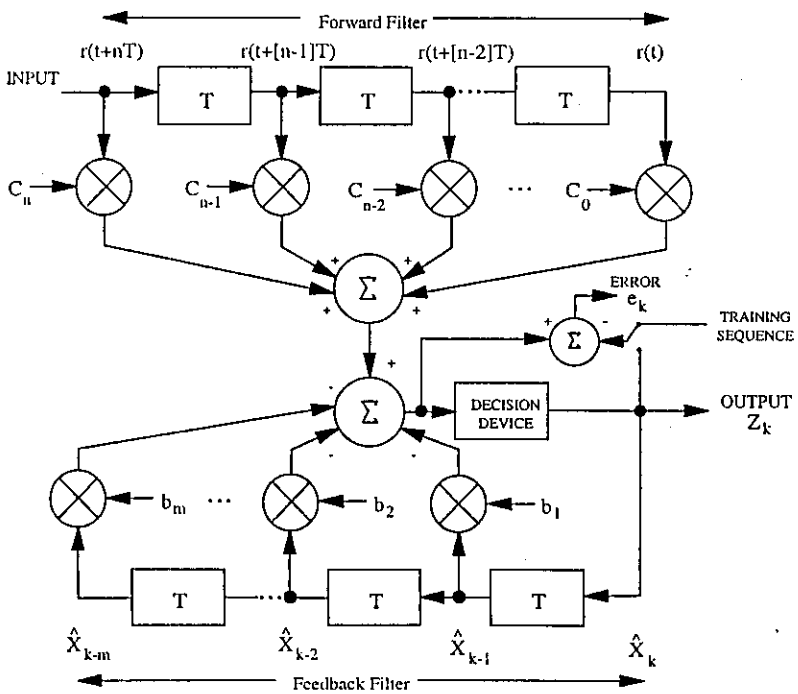


Equaliser Operation for a Typical Profile



- Since the past echoes are removed by the hard feedback filter, only the future echoes need to be cancelled by the noise enhancing forward filter.

Decision Feedback Equalisation



The DFE cancels ISI from past decisions without creating any noise enhancement

Errors made in the hard decision device are feedback through the equaliser and can produce error propagation, fortunately this is not catastrophic

The DFE can be thought of as two Transversal filters, one feedforward and one feedback

Equaliser Algorithms

LTE, DFE and Channel Estimator with MLSE

- LMS Gradient
- RLS (Kalman) Algorithm and its derivatives

(Equaliser training can be achieved using either the LMS algorithm or the faster and computationally intensive RLS algorithm)

Training Algorithm Selection Criteria

- Convergence Speed (Overhead)
- Complexity (Instructions per Iteration)
- Robustness to Channel Variations
- Numerical Stability