Communications

IB Paper 6
Handout 5: Multiple Access

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Lent Term

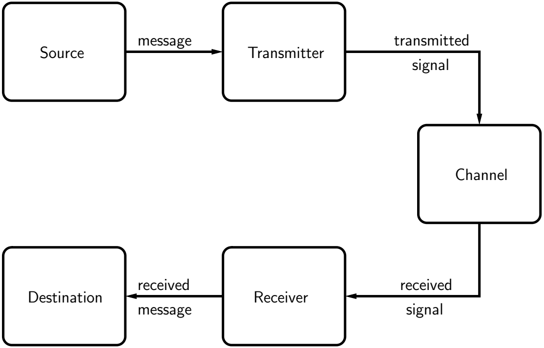
Outline

1. Introduction and Motivation
2. Multiple Access Techniques
   - Frequency-Division Multiple Access
   - Time-Division Multiple Access
   - Code-Division Multiple Access
   - Example: GSM
3. Course Summary
   - Important Topics
   - Relevant Past Tripos Questions

Introduction and Motivation

So far...

We have studied techniques for single user point-to-point communications.



Introduction and Motivation

Remember (Handout 4)

If we have one user we have that

$$y(t) = x(t) + z(t)$$

- $x(t), y(t)$ are the transmitted and received signals of bandwidth B
- $z(t)$ is the noise with flat power spectral density N_0
- the channel capacity is given by

$$C = B \log_2 \left(1 + \frac{P}{N_0 B}\right)$$

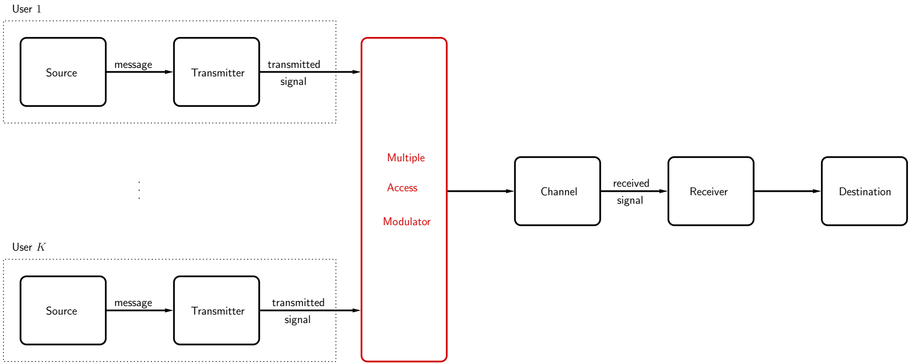
Multiple Access Techniques

What is Multiple Access?

Multiple access techniques

- are special modulation techniques to accommodate multiple users in a communications channel
- allow multiple users to share a finite amount of bandwidth

Multiple Access Techniques



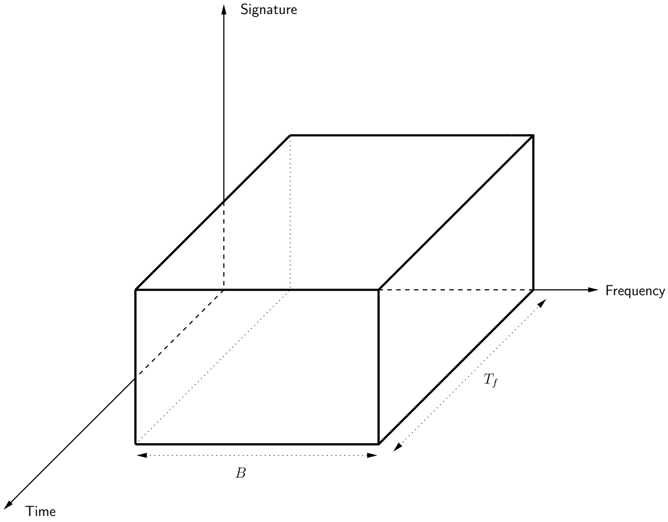
Multiple Access Techniques

Example

Imagine that all of you (multiple users) have a question (which may or may not be the same) to ask me (receiver). What techniques can we use, such that I understand all questions?

- One after the other (time-division multiple access), each using the whole bandwidth for a fraction of the time.
- All at the same time, but each with a different frequency (frequency-division multiple access), using a fraction of the bandwidth all the time
- All at the same time using the whole bandwidth, each with a different *signature* (code-division multiple access), i.e., a different language (known to the receiver)

Multiple Access Techniques



Multiple Access Techniques

Example

Other real-life examples include

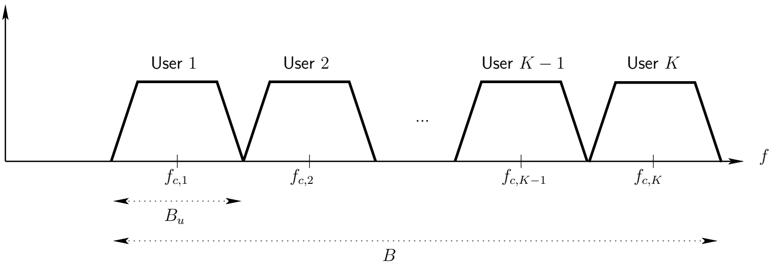
- Multiple cell phones desiring to call at the same time
- Multiple computers accessing the internet
- Multiple satellites transmitting to earth

Multiple Access Techniques

Frequency-Division Multiple Access

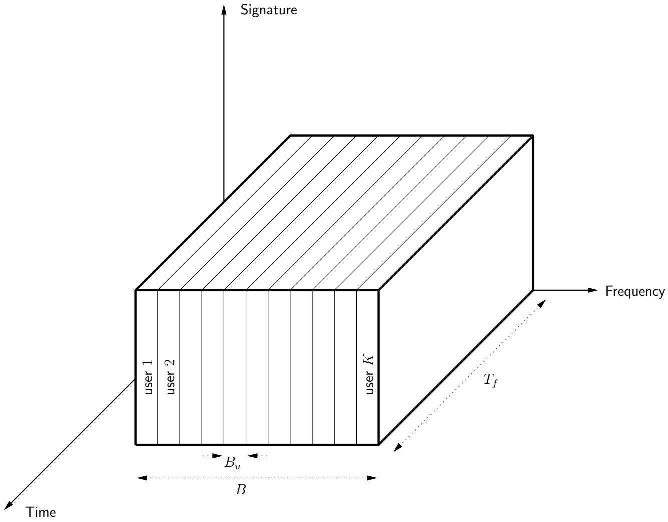
FDMA

Multiple users are multiplexed in the frequency domain, such that they do not interfere with each other, using a fraction of the total bandwidth. Essentially DSB-SC modulation for each user, such that spectrums do not overlap.



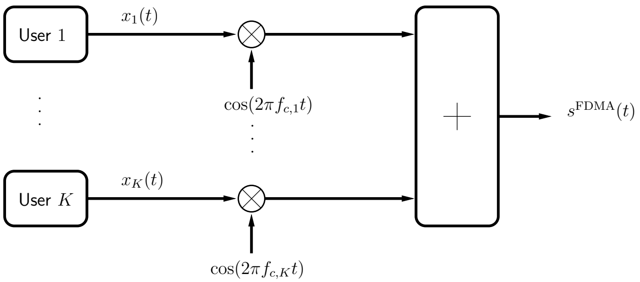
Multiple Access Techniques

Frequency-Division Multiple Access



FDMA

The time-domain signals get mixed together though...



Multiple Access Techniques

Frequency-Division Multiple Access

Capacity of FDMA

Assuming no overlap nor guard bands, i.e., $B = KB_u$ (see Figure) the capacity of each user is

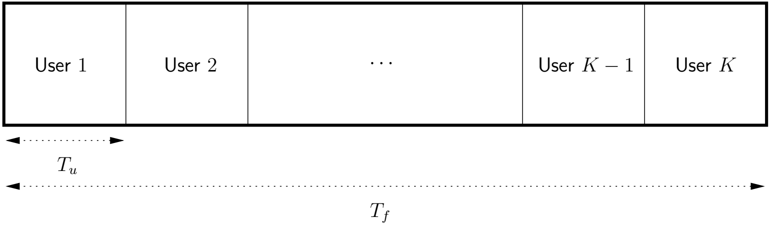
$$C_k^{\text{FDMA}} = \frac{B}{K} \log_2 \left(1 + \frac{P}{N_0 \frac{B}{K}} \right)$$
$$= B_u \log_2 \left(1 + \frac{P}{N_0 B_u} \right)$$

Multiple Access Techniques

Time-Division Multiple Access

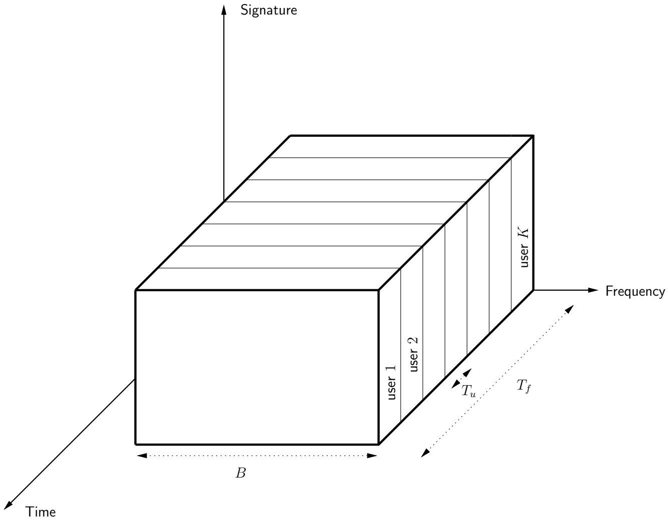
TDMA

Multiple users are multiplexed in time, so that they transmit one after the other, using the whole bandwidth B. We divide the *frame duration* T_f into K time slots of duration $T_u = \frac{T_f}{K}$.



Multiple Access Techniques

Time-Division Multiple Access



Multiple Access Techniques

Time-Division Multiple Access

Capacity of TDMA

Assuming no overlap nor guard intervals, i.e., $T_f = KT_u$ (see Figure) and users transmit with power KP when active (so that the average power per user is P), the capacity of each user is

$$\begin{aligned} C_k^{\text{TDMA}} &= \frac{1}{K} B \log_2\left(1 + \frac{PK}{N_0 B}\right) \\ &= B_u \log_2\left(1 + \frac{P}{N_0 B_u}\right) \\ &= C_k^{\text{FDMA}} \end{aligned}$$

Multiple Access Techniques

Code-Division Multiple Access

CDMA

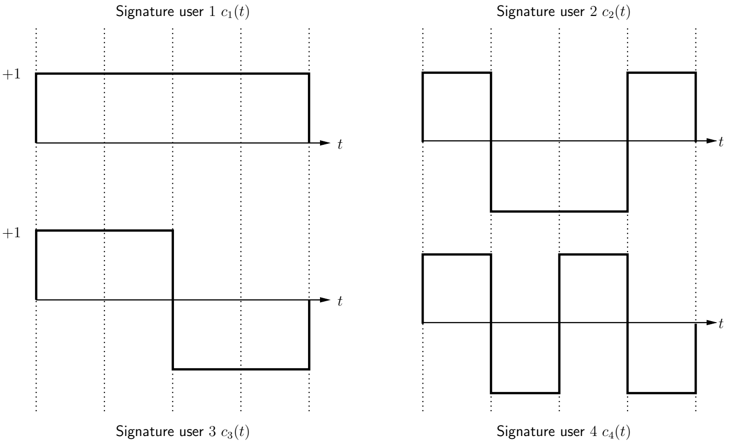
Multiple users are multiplexed in *code* or *signature*, and transmit using the whole bandwidth B over the whole time frame of duration T_f.

... but what is a signature?

A signature is a signal characteristic to each user, and known to the receiver. We denote the K signatures by $c_k(t)$ for $k = 1, \ldots, K$.

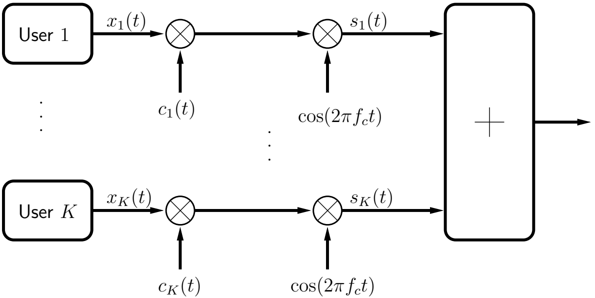
Multiple Access Techniques

Code-Division Multiple Access



Multiple Access Techniques

Code-Division Multiple Access



$$s^{\text{CDMA}}(t) = \sum_{k=1}^{K} c_k(t) x_k(t) \cos(2\pi f_c t)$$

Orthogonal Signatures

The received CDMA signal is given by

$$y(t) = \sum_{k=1}^{K} c_k(t)x_k(t)\cos(2\pi f_c t) + z(t)$$

where $z(t)$ is the noise signal. Assuming we have no noise (i.e., $z(t) = 0$) and perfect carrier demodulation we have

$$\tilde{y}(t) = \sum_{k=1}^{K} c_k(t)x_k(t)$$

where $\tilde{y}(t)$ is the demodulated signal.

Orthogonal Signatures

If we chose the signatures to be orthogonal, i.e.,

$$\langle c_k(t), c_j(t)\rangle = \frac{1}{T}\int_0^T c_k(t)c_j(t)dt = \begin{cases} 0 & j \neq k \\ 1 & j = k \end{cases}$$

we can recover the transmitted information by each user, by simply performing the following operations for all $j = 1, \dots, K$ (assuming that $x_k(t)$ are rectangular pulses)

$$\begin{aligned} \langle \tilde{y}(t), c_j(t)\rangle &= \frac{1}{T}\int_0^T \tilde{y}(t)c_j(t)dt \\ &= \frac{1}{T}\int_0^T \sum_{k=1}^{K} c_k(t)x_k(t)c_j(t)dt = \begin{cases} 0 & j \neq k \\ x_k(t) & j = k \end{cases} \end{aligned}$$

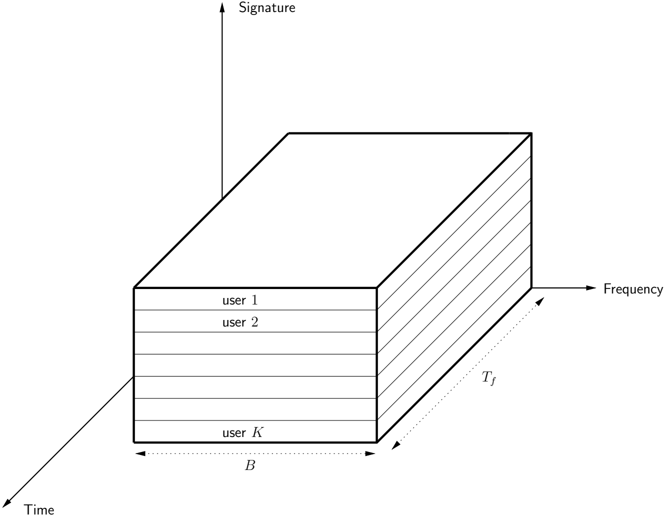
assuming $x_k(t)$ does not vary within the period T.

Orthogonal Signatures: Summary

If we chose the signatures to be orthogonal, the signals can overlap in both time and frequency and we are still able to recover the information of each user.

Multiple Access Techniques

Code-Division Multiple Access



Multiple Access Techniques

Example: GSM

GSM

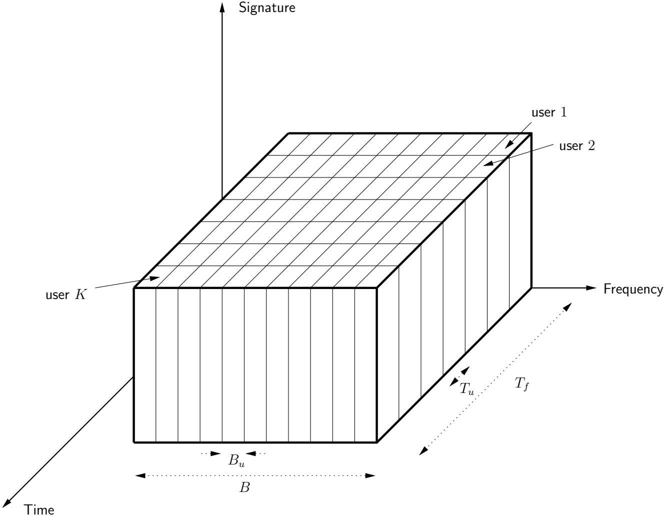
GSM uses a combination of both TDMA and FDMA, and assigns a time slot and a frequency carrier to each.

GSM

In order to minimise the distortion due to fading (mobility, multipath propagation) GSM changes the time-frequency allocations assigned to different users during transmission.

Multiple Access Techniques

Example: GSM



Course Summary

Important Topics

1. Communications Channels
   - Convolution
   - Noise
   - Multipath and Doppler (coherence bandwidth and time)
2. Analogue Modulation
   - AM, DSB-SC, SSB-SC (properties, differences, spectrum, power)
   - FM: Carson's rule
3. Digitisation
   - Sampling
   - Quantisation (quantisation noise)
   - Representation of digital signals and spectrum
4. Digital modulation ASK, FSK, BPSK (spectrum, error probability)
5. Channel capacity
   - Concept of rate and channel coding
   - Channel capacity
6. Multiple-Access (FDMA, TDMA, CDMA)

Course Summary

Relevant Past Tripos Questions

- 2012 Paper 6, Questions 5 and 6
- 2011 Paper 6, Questions 5 and 6
- 2010 Paper 6, Questions 5 and 6
- 2009 Paper 6, Questions 5 and 6
- 2008 Paper 6, Questions 5 and 6
- 2007 Paper 6, Questions 4 and 5
- 2006 Paper 6, Question 5
- 2005 Paper 6, Question 5
- 2004 Paper 6, Question 6
- 2003 Paper 6, Question 5 excluding the final two lines of part (d).
- 2002 Paper 6, Question 5
- 2002 Paper 6, Question 6 except part (c).
- 2001 Paper 6, Question 6