Preliminary Report

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Contents

Meta-Description

The preliminary report is effectively a summary of progress at the end of Teaching Period 1, and a plan of the intended work during Teaching Period 2.

The preliminary report should not exceed 15 pages (excluding the log book), and MUST contain the following:

- a brief summary (1 page maximum) of the achievements to date.
- a description of the project, including the main aims and/or objectives.
- an introduction, putting the project into context with other work in the same subject area, incorporating a comprehensive review of relevant literature, including references to books, journal articles, conference proceedings, manuals, and the Internet.
- Evidence of use of the library and online databases should be included.
- an individual project plan for each student for the intended work during Teaching Period 2, including specific aims, goals and timescales, and a clear division of labour for students working together on a joint project. A Gantt chart or similar visualization aid should be included.

- a detailed discussion of any ethical issues (environmental, societal, legal, professional or medical) that may be applicable to the proposed research, and any relevant industrial standards and Health and Safety requirements.

Colin's Tips:

- Focus on what you've learnt so far
- Provide a detailed breakdown of how you expect to proceed in TP2, this will be compared with the final report
- 2nd examiner may not be familiar with comms

Summary of acheivements to date

- The author has familiarised himself with relevent communications theory, including modulation schemes, probability theory and optimum detector design.
- The author has become acquainted with the Mathematica programming environment and used it to program a number of mathematical simulations describing communications problems.
- The author has examined the effects of receiver timing error on BPSK and 4-PAM modulation schemes using root raised cosine filters, and demonstrated sub-optimal detection performance with 4-PAM using standard detector designs.
- The author has characterised the change of optimum decision region boundaries in the presence of non-deterministic timing errors following a known probablistic model.

Introduction and background to the project

This project seeks to examine the effects of receiver timing error in radio communications systems. Understanding how radio system performance decreases in sub-optimal conditions is key to assessing a system's performance and designing more robust and performng radio systems. The author hopes to be able to characterise the effects of timing error such that a receiver may be optimised to account for it.

A typical radio communications system consists of a transmitter, a receiver and a communications channel, that may contain any number of non-idealities. For this reason, if a transmitter sends a particular symbol down a real communications channel, the received symbol may be substantially different to the sent symbol. Therefore, careful attention is required to the design of the receiver symbol detector.

If we imagine a binary transmission system that sends one of two possible signals: a 1V$_{RMS}$ wave if a '0' is to be sent, and a 3V$_{RMS}$ if a '1' is to be sent. After being distorted by the communications channel, the receiver could in theory see a signal of any amplitude, an must make a decision as to what amplitude was originally sent. It would be helpful to know the probability density function (PDF) of the received signal, ie. the probability of receiving a signal amplitude if a known amplitude was sent. If we assume the communications channel distorted the signal by adding zero-mean white Gaussian noise, the received signal PDF will be a Gaussian distribution centred on the sent signal amplitude.

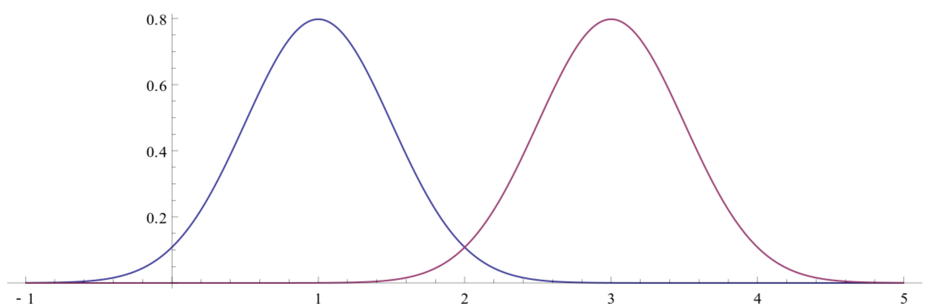

Figure 1: Gaussian noise corrupts a sent signal, resulting in a probability density function for each possible sent symbol

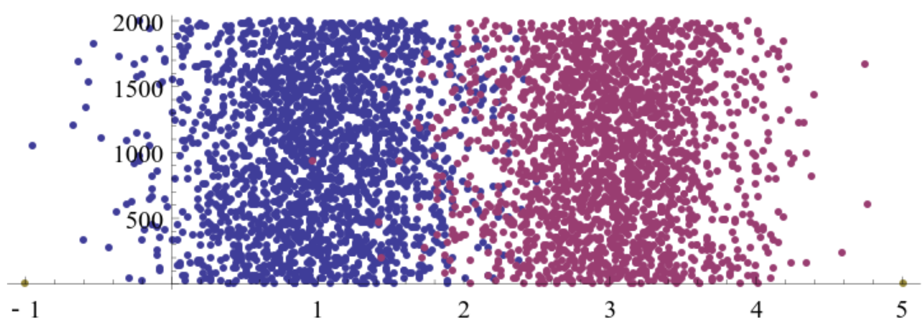

Figure 2: As an example, 2000 of each symbol has been send down the communications channel. The received values distorted by noise are plotted above. Note the overlap in received values corresponding to both symbols: it is impossible to detect the signal with 100% accuracy.

An ideal detector would always pick whichever signal was most likely to be sent. Therefore, the treshold between picking one value or the other will be where both symbols are equally likely to be sent, the point of intersection of both PDF's. Since the Gaussian distribution is symmetric about its mean, in this case the treshold (or **Decision Region Boundary**) is exactly midway between both sent amplitudes. Intuitively this makes sense: it says that if we receive a signal amplitude, we should assume whichever possible sent amplitude is nearest. However this is not generally the case, and in more complicated cases picking the point of intersection of both PDF's is a good solution.

One issue that complicates detection is **inter-symbol interference** (ISI). It is possible for signals representing symbols in the future or past to bleed into the current symbol clock period, distorting the signal further. For this reason transmtters and receivers are designed such that they apply a **raised cosine function** that is fully transparent at exactly the symbol's sample time, and blocks completely at every other symbol's sample time, ie at every interval of T_{clk} for $T \neq 0$. If both receiver and transmitter are perfectly synchronised, this ensures that the receiver will only see signals corresponding to the current transmitted symbol, after distortion via the communications channel.

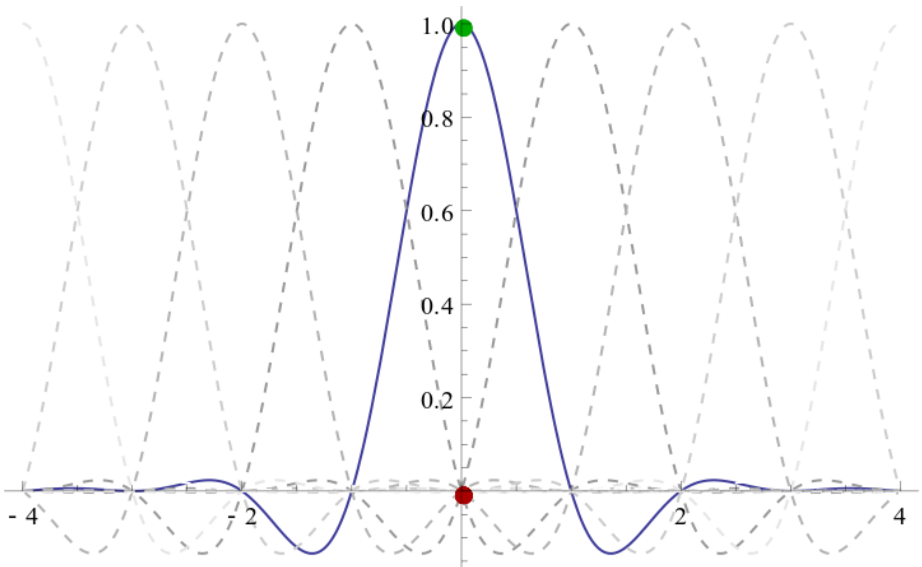

Figure 3: A filter with a root raised cosine function is often used, as it evaluates to 1 at the current sample time and 0 at all other sample times

If the receiver and the transmitter are poorly synchronised, however, the root cosine filter response is shifted in time with respect to the receiver and looses some of its essential property. Current literature has considered... However, the effects of a poorly synchronised receiver on detection performance has not to date been publicised. This project seeks to examine this matter further, and ascertain whether design decisions can be made to mitigate its effects.

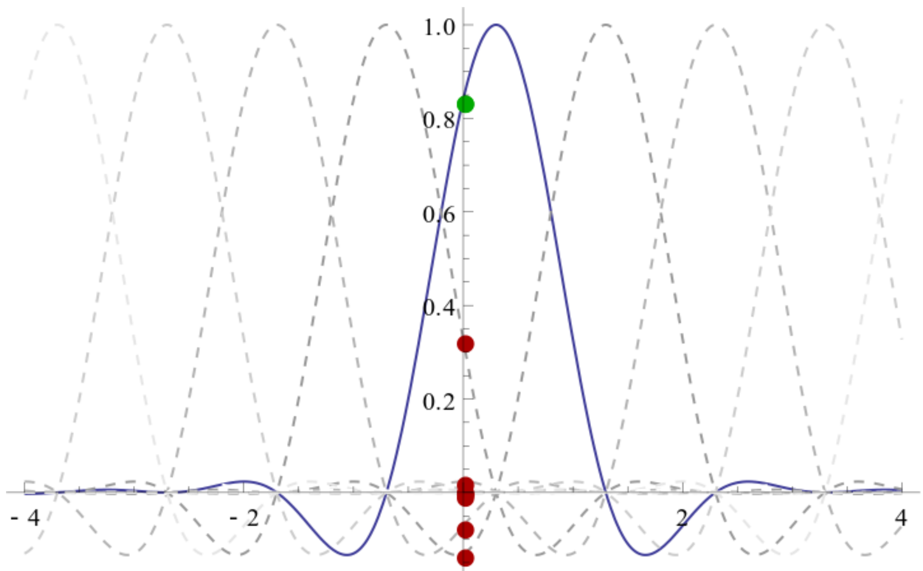

Figure 4: If a timing offset is added to the root raised cosine it no longer evaluates to 0 or 1 at the sampling points. This results in reduced receiver performance when the receiver and transmitter are not properly synchronised.

Description of the project

To get started on the project I began by reading up on the underlying theory. I consulted Proakis *(ref)* and learnt about probability theory, coding theory and optimum receiver design. I became familiar with the concept of representing received signal characteristics using probablistic models, and the rationale for doing so in the Additive White Gaussian Noise (AWGN) case described before. I learnt about designing receivers using both Maximum Likelihood and Maximum A Posteriori optimisation, and how this might be done using a known probablistic model for the received signal. I also spent some time understanding research done by a UCC graduate, David McCarthy, into estimating these probablistic models using a Gram-Charlier probability distribution. Additionally, I started learning the Mathematica language from scratch, with emphasis on statistics and plot generation.

In order to familiarise myself further with these concepts, I built a simple model for a two-symbol BPSK communications system in Mathematica. I extended this to the 4-symbol 4-PAM system. With some help I also implemented the Gram-Charlier distribution. Using these programs as a base I then wrote a simulation that would a PDF of the receiver input with a known timing offset. Using this, I was able to examine how the sent symbol is distorted by the channel and timing error, and found that increasing amounts of offset reduced the effective amplitude of the signal while increasing noise due to ISI. Additionally, it was found that the optimum decision region boundary was decreased by a factor equal to the value of the root raised cosine function at the timing offset.

My attention at this stage turned to increasing the speed of the simulations, and much work was done studying Mathematica's potential for parallisation. I was able to acquire remote access to a number of Unix machines, and ported the simulations to run across multiple machines, paying attention to taking advantage of the dual-core processors and making the code robust to premature termination (due to power outages, illiterate students etc.).

A more realistic model was created by assuming that the timing error is not a fixed value, but could be described by a Tikhonov distribution. Two approaches were taken: an initial, quick approach was to calculated the optimum decision region boundary of each timing error, and average this over the probability of each timing error occuring. This assumes that multiple possible optimum decision region boundary locations could be averaged to give the overall optimum decision region boundary location, which I learnt was not generally the case, and this was later proven analytically by David. I therefore tried a second, more realistic approach, where for each simulated transmission a new timing offset was chosen from the Tikhonov distribution. An optimum decision region boundary was then determined for multiple Tikhonoc distribution widths (or variances). It was found that the optimum decision region boundary decreased as the variance of the Tikhonov distribution increased.

To summarise, my work in TP1 helped introduce me to radio communications systems, and concepts of signal corruption and optimum detectors. I learnt how to translate signal transmission into mathematical simulations, and how to extract meaningful conclusions from the output. Using the theory and simulations developped during this time I was able to demonstrate a changing optimum decision region boundary in the presence of a non-deterministic timing offset using 4-PAM signalling. It is believed this behavior can be generalised to L-PAM signalling. This will serve as a foundation from which to explore the effects of a non-deterministic timing offse in more general cases.

Plan for Teaching Period 2

In TP2, I aim to extend the scope of my project to address the issue of timing error offset in communications channels subject to fading effects such as in urban areas or for very long-range communications. In either case, line-of-sight communication is very weak or non-existant, and the signal is scattered and received as a combination of multiple "bounced" signals with different propagation delays and amplitudes. I will model these using a Rayleigh distribution, and asuming an Equal Gain Combining (EGC or additive) receiver, determine the effects of timing error described above on this type of model. I will stick to L-PAM signalling, as PSK signalling formats rely solely on phase detection and therefore the optimum decision region boundaries are unaffected by amplitude changes.

Once we have a description of the optimum detector in the presence of Rayleigh fading, the next goal will be to compare it to the optimum detector described in (*ref*), which assumes perfect synchronisation (ie. no timing offset).

A project plan is presented here as a guide to how work is expected to proceed in TP2. This plan is to be considered a mere guide, as Hopfstadter's Rule ensures that no project plan can be accepted as gospel truth. In order to account for this timescales have been made purposefully conservative. Should the work laid out below be terminated early, additional exploration of the effects of non-deterministic timing error on other communications systems will be undertaken.

Description	Time Allowed	Start Date	Goals
Review of Rayleigh fading	1 week	6 Jan	• Develop an understanding of Rayleigh fading. • Have built a basic Mathematica model of Rayleigh fading assuming perfect synchronisation.
Implement Rayleigh fading model with timing error	1 week	13 Jan	• Extend previous model to account for timing errors following a Tikhonov distribution model. • Evaluate optimum decision region boundary in the presence of timing error offsets and Rayleigh fading.
Additional simulation time	1 week	20 Jan	• Characterise the effect of non-deterministic timing error on the optimum decision region boundary for L-PAM signalling in the presence of Rayleigh fading.
Compare described receiver to optimum receiver described in literature (*ref*)	2 weeks	27 Jan	• Provide a detailed comparison of the optimum described above, to the optimum receiver described in (*ref*), paying particular attention to performance in the presence of non-deterministic timing error.

(*insert Gantt chart here - pdfgantt*)

Discussion of ethical issues

In communications systems, as in any area seeing considerable technological developments, the question of whether these developments are ethically sound naturally arises. The advent and spread of radio throughout the 20th century brought about an era of increased connectedness and information transfer, as information could be rapidly spread across large distances with little effort. The advent of the internet in 1969 (*disputed - check this*) and the mobile phone boom of the 90s accelerated these changes as almost-instant, asynchronous and on-demand information transfer became available to the general public, and current Web 2.0 developments such as social networking are but continuations of this trend. With the smart-phone industry putting internet access into the pockets of consumers, many believe that these changes, driven by advances in communications technology, have had a considerable impact on our societies. While the positives are too numerous to note, the skeptic would also readily see the disadvantages.

Engineering developments can lend themselves to applications with both positive and negative intentions, as with any scientific advancement. Improving wireless communications can play into the hands of military and terrorist leaders, as cheap and reliable wireless communications can aid the organisation and execution of manoeuvres. In addition the remote detonation of explosives using mobile phones is considered a real threat to many cities. (*ref*) Increase in mobile cell phone usage has also helped drug trafficking (*check*) gangs, as they are able to operate a decentralised operation with little face-to-face communication. (*ref*)

Paradoxically, these same developments have created privacy concerns as most citizens find themselves communicating through the internet and the cell phone network. At the bottom of the internet heirarchy, endpoint routers are naturally trusting, and prone to exploitation; in addition, they are generally visible to all other internet users. At the top, most communications are routed through a small number of Tier 1 networks. As the distance over which an individual can send a piece of information to its intended recipient has increased, so has the number of individuals capable of intercepting this information. Thus as users embrace the internet and smart phones, they also find themselves increasingly exposed to spying from a number of groups with varying intentions. Even outside of the "online" world, increasing the efficiency of radio receivers can lead to the exploitation of security-sensitive short-range communications. For example, contactless payment devices rely on short range communications to transfer identification information for payment purposes. Equipped with a suitable exploit, a high-accuracy receiver would increase the number of these devices in range of an attacker.

The author notes that these issues relate to the broad area of communications within which this project falls. However he does not feel there is a direct ethical concern with any of the work described within here.

(*See http://www2.unescobkk.org/elib/publications/ethic_in_asia_pacific/239_325ETHICS.PDF*)