UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA
Faculty of Engineering, Built Environment and Information Technology

ESC 320

Stochastic Communication Systems

Practical 3 Guide

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with inputs from ESC 320 assistants

I. Description

A. Receivers

The RTL-SDR software-defined radios (SDRs) issued to students should be used for this assignment. Students will only be allowed to use alternative receivers with written permission from the lecturer.

B. Signal Parameters

The parameters common to all of the signals are provided below.

- The carrier frequency is 1.3 GHz.
- The symbol rate is 100 000 bit/s.
- The modulation is differential binary phase-shift keying (DBPSK) with the constellation diagram shown in Figure 1.
- The encoding schemes used in the transmitted signals are listed below in the order in which they are transmitted in a burst.
  1) The first burst uses a root-raised cosine bit shape to allow matched filtering to be performed.
  2) The second transmission uses Huffman coding to compress the data. The Huffman tree used is provided in Figure 5, which is in Appendix D.
  3) The third transmission uses linear block coding for error detection and correction. The generator matrix used for linear block coding is given by

$$\mathbf{G} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix}. \tag{1}$$

  4) The fourth signal uses convolutional coding for error correction. The convolutional code takes two bits as input per symbol and generates five output bits per symbol as shown in Figure 2.
- There are gaps between each of the bursts during which there are no transmissions.
  - There is a short gap between each burst.
  - There is a long gap (four times as long as the short gap) following the last burst listed above, after which the pattern of bursts repeats.
- The first 10 symbols in each case are the unmodulated carrier.
- A raised cosine bit shape with $\beta = 0.5$ is used, except for the first burst, where a root-raised cosine bit shape with $\beta = 0.5$ is used. It is thus not necessary to apply a matched filter to the final three signals.
- Each signal starts with a number of 8-bit American Standard Code for Information Interchange (ASCII) characters[1] with the first and last ASCII characters being a caret ("^" which is ASCII character 94) and a dollar symbol ("$" which is ASCII character 36).[2] The remaining bits are randomly-generated and will not correspond to ASCII characters except by chance.

[1]These characters contain short jokes obtained from https://onelinefun.com.

[2]The caret and dollar characters are used to denote the start and end of a line in regular expressions.

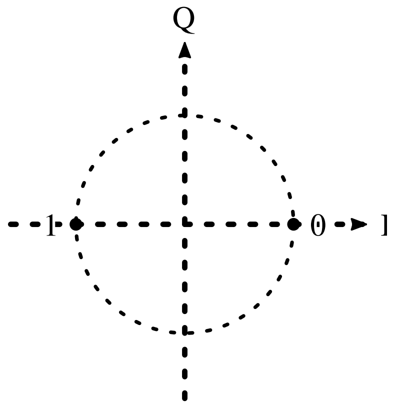


Figure 1: The constellation diagram for the DBPSK modulation used.

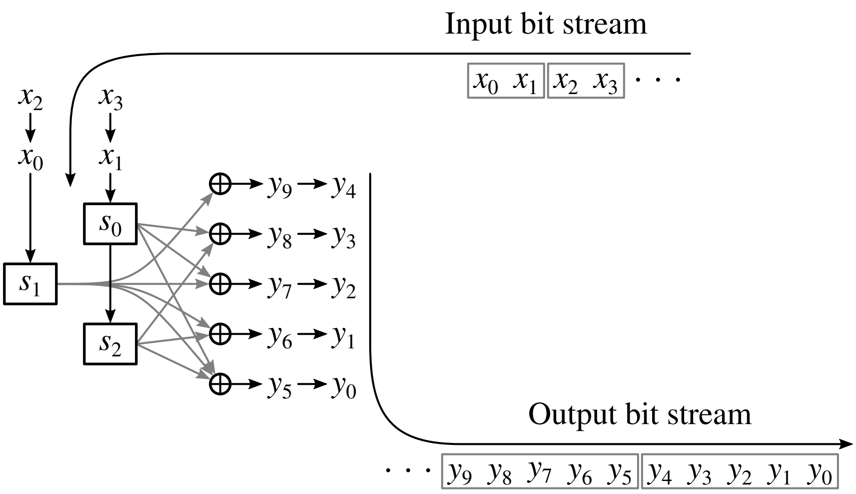


Figure 2: The convolutional encoder used to generate the fourth burst. Two bits of the input stream (x_n) are processed for each symbol, producing five bits of the output stream (y_n) for each symbol. The state (s_n) is updated on the basis of the input bits (s_0 and s_1), and one of the previous symbol's bits (s_2).

II. Instructions

The objective of this practical is to record transmitted signals using digital receivers and decode a number of different encoding schemes. Huffman coding is used to compress the data, while linear block coding and convolutional coding are used for error detection and correction. Students should also decode the transmitted ASCII characters.

The general instructions in Appendix C must be followed.

Note that the following tasks are not required for this assignment.

- It is not necessary that the code written for this assignment run in real time. The goal of the assignment is to implement a working system and not to optimise code.
- It is not necessary for the implemented system to automagically determine the start of each burst, and this value may be determined by the user.[3]

[3]A well-implemented algorithm should be capable of rapidly locking onto a signal following the gaps between bursts, so the start times of each burst are not strictly necessary for this assignment.

A. Report Content

Each group is required to submit a report providing the information listed below.

- At least the first 10 ASCII characters must be determined for all signals.
- A description of the processes followed to decode each of the signals, including any necessary mathematics and diagrams.
- The code redundancy and efficiency of the Huffman encoding should be computed.
- The number of bits which can be detected and corrected with the specified linear block code should be determined.
- For both the linear block code and the convolutional code, any bits which are incorrectly received must be indicated, and the corrected values provided for at least ASCII characters 1 to 5.
- It is only necessary to provide the trellis diagram for ASCII character 5 of the convolutional code.
- Any computer code written to obtain the results presented in the report should be included in appendices.

Marks will be awarded primarily on the basis of the explanations and motivations provided. Merely obtaining the correct result is not nearly as important as describing how the result was obtained. The mark allocation for the report is provided in Appendix B.

B. Examples of Exceptional Results

Examples of excellent figures are provided in Section III. Students are also welcome to plot the results in different graphs rather than in subfigures as in Section III. The plots in Section III correspond to obtaining a high mark,[4] and are not the minimum acceptable standard.

As stated previously, please remember that marks will primarily be awarded for the motivations for what was done rather than just what was done. For example, the procedure to synchronise with the received carrier ensures that the constellation points do not rotate around the centre of the diagram, and a description of how this was achieved is more important than the fact that it was achieved.

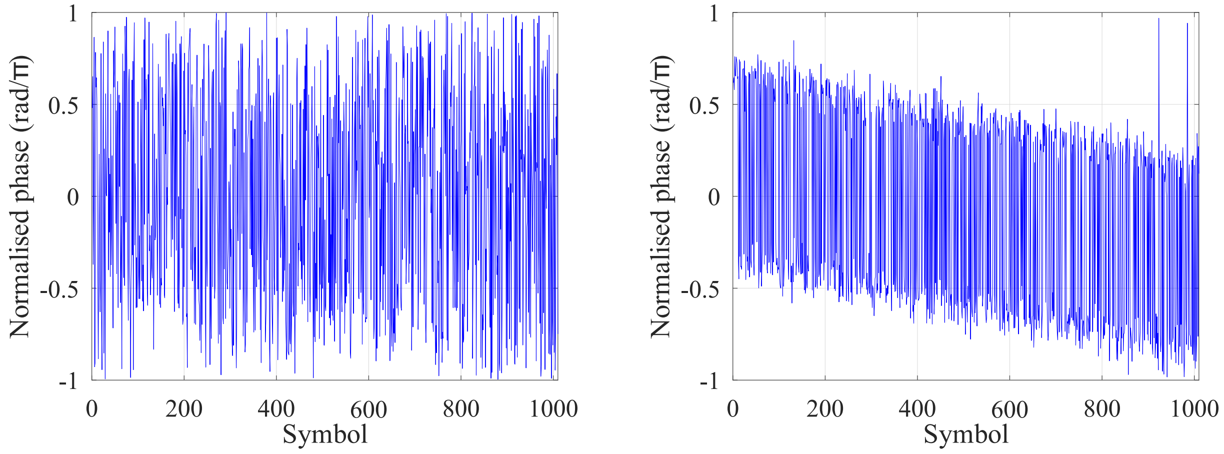
III. Guide

This section provides a brief guide to how the practical can be approached. The suggestions below are not the only ways to achieve the required outcomes, and other, better approaches may exist.

All the examples in this section assume that the character sequence "^A joke.$" was transmitted.

A. Matched Filtering

The effect of a matched filter on a signal is shown in Figure 3 by plotting the phase of the symbols. The same data with identical sampling instants were used, and inter-symbol interference (ISI) was avoided by considering a raised-cosine shape in both cases (transmitted pulse shape in Figure 3(a), and after matched filtering in Figure 3(b)). The effect of the matched filtering is clearly shown by the reduction in the noise on the signal. While there is no clear pattern to the phase in Figure 3(a), the 180° phase variations are clearly visible in Figure 3(b).



(a) No filtering

(b) Matched filtering

Figure 3: The effect matched filtering on the phase of sampled symbols of a signal.

TABLE I: Huffman Coding Results

Bits	00100011	0110	000	100010010	0111	1000101	110	0010000	00100010
Characters	^	a	*space*	j	o	k	e	.	$

TABLE II: Linear Block Coding Results

Received	000101	101001	110011	110011	000010	000011	101011	000001
Syndromes	101	101	101	101	010	011	111	001
Errors	010000	010000	010000	010000	000010	100000	001000	000001
Corrected	0**1**0101	**1**11001	1**0**0011	1**0**0011	0000**0**0	**1**00011	10**0**011	00000**0**
Bits	010	111	10 0	100	000	1 00	100	000
Bytes		0101 1110			0100 0001		0010 0000	
Values		94			65		32	
Characters		^			A		*space*	

B. Huffman Coding

An example of results using Huffman coding is shown in Table I.

C. Linear Block Coding

An example of results using linear block coding is shown in Table II.

Error correction using linear block coding is achieved using a parity-check matrix to compute the syndromes, which are used to determine the bits which are in error. The errors are then corrected, after which the data bits can then be extracted.

D. Convolutional Coding

An example of results using convolution coding is shown in Table III, with a portion of the trellis diagram shown in Figure 4.

TABLE III: Convolutional Coding Results

Received bits	10110	01000	10011	00111	10110	11010	00000	01110
Corrected bits	10110	01**1**00	100**0**1	00111	10110	11010	00000	**10**110
States (s_2, s_1, s_0)	001	101	111	110	001	100	000	001
Data bits (x_0, x_1)	01	01	11	10	01	00	00	01
Bytes	0101 1110				0100 0001			
Values	94				65			
Characters	^				A			

The convolutional encoder can be assumed to start in state 000. However, it is important to note that this is only true before the very first bit. A convolutional decoder must start from the previous state to obtain the correct results. This is important because any implementation of a convolutional decoder which processes a limited number of bits at a time because its initial state must be set to the final state of the previous bits which were decoded.

It can be seen that two of the final nodes in Figure 4 have total errors of 4. This was not a problem here because the Vitterbi decoder used all the received data, while only the first 16 bits are shown in Figure 4. This apparent ambiguity is resolved by later decoding steps which are not shown in Figure 4. Another alternative is to continue decoding until the ambiguity is resolved [1].

It is worth noting that terminating the decoding too early can lead to difficulties where the correct path initially has an initially high error count which reduces over time. Stated differently, convolutional decoding does not always select the nodes with the fewest errors at each step. Sometimes a node with a larger error than the other nodes at the same step will end up being selected because it is on a path which leads to fewer errors later on.

References

[1] B. P. Lathi and Z. Ding, *Modern Digital and Analog Communcation Systems*, 4th ed. Oxford, UK: Oxford University Press, 2010.

[2] W. P. du Plessis, *ESC 320 – Practical 2 Guide*, University of Pretoria, 28 Jul. 2020.

[3] W. P. du Plessis, *ESC 320 – Practical 1 Guide*, University of Pretoria, 28 Jul. 2020.

[4] (2019, 31 Aug.) Letter frequency - Wikipedia. Wikimedia Foundation, Inc. [Online]. Available: https://en.wikipedia.org/wiki/Letter_frequency

[5] (2019, 31 Aug.) Letter frequencies per 1000 words. Trinity College. [Online]. Available: http://www.cs.trincoll.edu/~crypto/resources/LetFreq.html

[4] That said, the font sizes in the figures in Section III are slightly on the small side.

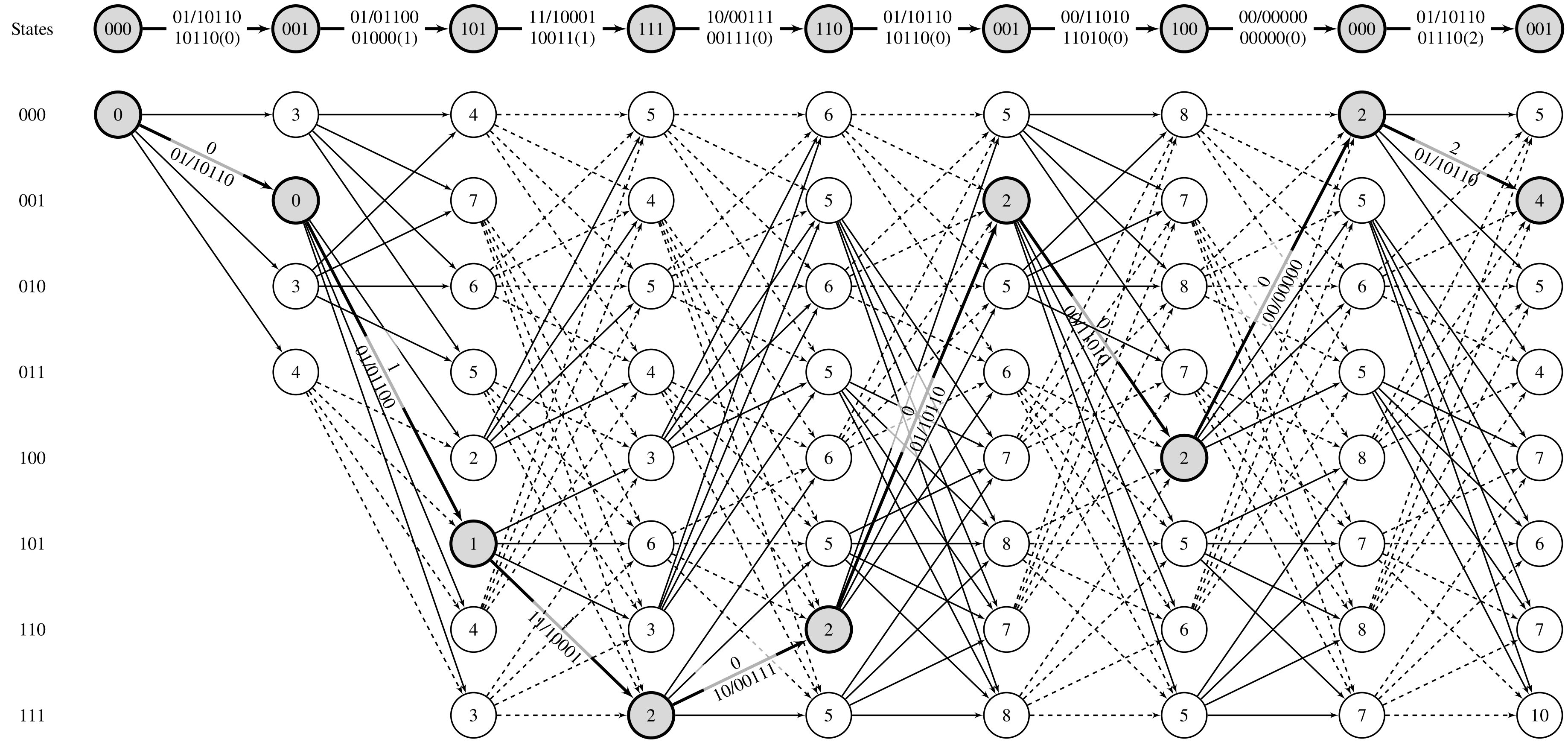


Figure 4: A portion of the trellis diagram used the generate the convolutional coding results. Note that this figure considers 16 bits (2 bytes), but students are only required to consider a single byte of 8 bits.

Appendix A
Abbreviations

AL	Assistant Lecturer
ASCII	American Standard Code for Information Interchange
DBPSK	differential binary phase-shift keying
ISI	inter-symbol interference
SDR	software-defined radio

Appendix B
Report Mark Allocation

The mark allocation for the report for this practical is shown in Table IV.

Please take note of the following points.

- Methodology should include all theory, calculations, and code flow diagrams used to obtain the results. Where information is reused, referring to the relevant section of the report is acceptable.
- Results should include all obtained results and figures corresponding to those in the practical guide.
- Discussion should include thorough, critical analyses of the obtained results. Observations, and especially anomalies, should be discussed and explained.
- All code that is used to obtain and output the results should be attached as an appendix to the report. Code should be easy to read and well-commented.
- For the formatting, the following points need to be adhered to:
  - a table of contents, introduction and conclusion should be present,
  - the required plagiarism declaration should be added,
  - correct spelling and grammar should be used,
  - figures should be labelled correctly and each figure should be introduced, and
  - all information obtained from external sources (including figures) should be referenced using in-line referencing.

  Students are advised to consider using LaTeX it addresses many of these issues are automatically.

TABLE IV: Practical 2 Report Mark Allocation

Topic	Total	Methodology	Results	Discussion
Matched Filter	23	6	6	11
Huffman Coding	15	4	4	7
Linear Block Coding	22	6	6	10
Convolutional Coding	25	8	7	10
Language and formatting	10			
Code	5			
Total	100			

Appendix C
General Instructions

This appendix contains general instructions which are applicable to all assignments.

- While no specific format is prescribed, this is a formal report so the requirements for formal reports should be followed (e.g. numbered sections, introduction and conclusion, numbered figures and tables, etc.).
- Only ONE student in each group should submit the report because TurnItIn will flag reports as having 100% similarity if more than one student submits a group report.
- Reports must be submitted via the ESC 320 ClickUP page. Do not email reports to the lecturer or Assistant Lecturer (AL) as emailed reports will be considered not to have been submitted.
- The names of submitted files must have the format shown below.
  `esc320_prac_2_{student number 1}_{student number 2}.{extension}`
- No late assignments will be accepted. No excuses for late submission will be accepted.
- Each student must do their own work. Academic dishonesty is unacceptable and cases will be reported to the university Legal Office for suspension.
- The report must include the standard declaration of originality for group assignments provided in the General Study Guide of the Department of Electrical, Electronic and Computer Engineering.
- All information from other sources must be clearly identified and referenced.
- Any computer code used to obtain the results presented in the report should be included as appendices.

A. Submission

Reports should only be submitted via the

- `Practicals → Practical 2 → Report`

links on the ESC 320 ClickUP page. Only assignments submitted in via ClickUP will be accepted. Do not email reports to the lecturer or AL as emailed reports will be ignored.

The names of submitted files must have the format shown below.

```
{course code}_prac_{practical number}_
                    {student number 1}_{student number 2}.{extension}
```

Late submissions will not be accepted! Accepting late submissions is extremely unfair on those students who submit their work timeously because their tardy colleagues are effectively given additional time to complete the same work. Students are advised to submit the day before the deadline to avoid inevitable problems with ClickUP, internet connections, unsynchronised clocks, load shedding, hard-drive failure, computer theft, etc.. Students who choose to submit close to the deadline accept the risk associated with their actions, and no excuses for late submissions will be accepted.

Students will be allowed to submit updated copies of their assignments until the deadline, so there will be no excuse for submitting late. Rather be marked on an incomplete early version of your assignment than fail to submit anything.

B. Academic Dishonesty

Academic dishonesty is completely unacceptable. Students should thus familiarise themselves with the University of Pretoria's rules on academic dishonesty summarised in the study guide and the university's rules. Students found guilty of academic dishonesty will be reported to the Legal Office of the University of Pretoria for suspension.

Students are required to include the standard originality declaration for group assignments provided in the General Study Guide of the Department of Electrical, Electronic and Computer Engineering as part of their reports. This standard originality declaration includes a statement that the group submitting the report is aware of the fact that academic dishonesty is unacceptable and a statement that the submitted work is the work of that group. Failure to include this declaration of originality will mean that the submission will be considered incomplete.

While students are encouraged to work together to better understand the work, each group is required to independently do their own work (including recording signals, processing signals, writing the report, etc.). No part of any group's work may be the same as any part of another group's work.

Students should clearly indicate material from other sources and provide complete references to those sources. Examples of commonly-used sources include the textbook [1], this document [2], and the guide for the first practical [3]. Note that this does not mean that students may reuse code and/or information found in books, on the internet (e.g. GNU Radio), or in other sources as students are required to complete the tasks themselves.[5] Reusing code to perform ancillary tasks such as interfacing with a SDR, reading files, and plotting images is acceptable as long as the portions of the code which are reused are clearly marked (normally comments indicating the start and end of such code, along with its source are sufficient).

[5] The objective of all academic assignments is fundamentally that students learn by completing the assignments. Merely reusing code and/or information found elsewhere defeats this objective because a key part of the learning process is performing the tasks oneself.

Appendix D
Huffman Coding

The letter frequencies used for this assignment were obtained from [4], and the average length of an English word of 4.5 letters was obtained from [5]. It was assumed that the average sentence is 15 words long, a comma appears in every second sentence, every tenth sentence uses inverted commas, every twentieth sentence is a question, and each message has two sentences.

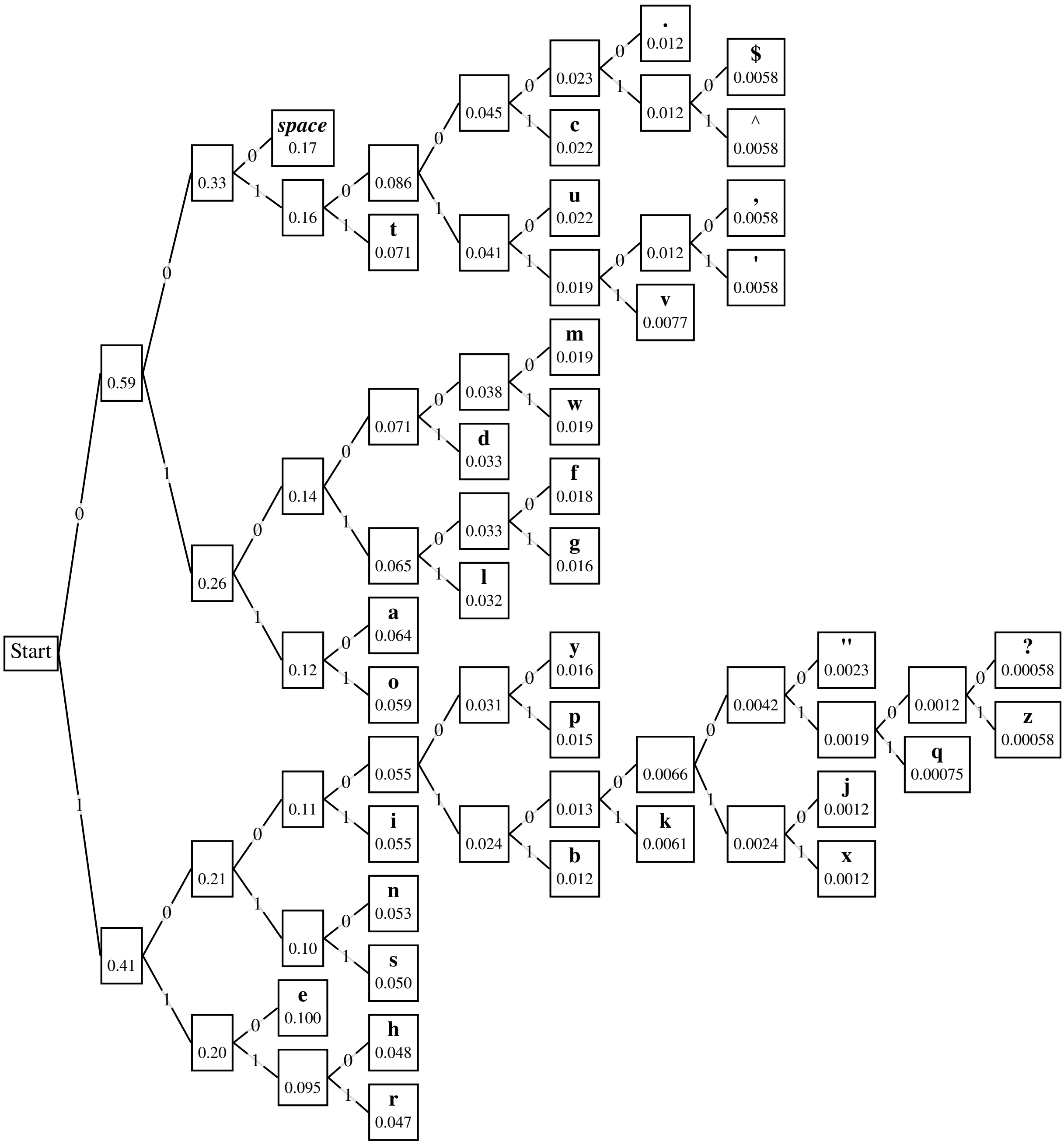


Figure 5: Huffman tree used to encode text characters. The lines in each box are the character and the probability, respectively.