By Adam Johnstone – GLJD44

AI Critique

Prompts:

Prompt 1:

I would like for you to please write an in depth Literature Review surrounding the project title of 'Cryptanalysis of Retro Block Ciphers' and the research question 'is the sandwich attack feasible for breaking the GOST block cipher?' you should also follow the guidelines below: Typically the first page is used to define your terms and to give references to where you found the definition. For example, on a project on safety critical systems, it would be essential to define very carefully safety critical systems' and other terms such as safety', reliability', error free', and so on. The next three pages should be used to select some themes. If your project was about compiler parsers, good themes might be: parsing algorithms, tools, language classification. You then give a succinct, careful description of each of these as if you were addressing an experienced computer scientist who was not an expert in the area. As your description develops, cite references to books/papers where you found the information. Finally use the last page to assess the themes, draw some conclusions and show how you will use it in your project. please include as much detail as you feel is necessary to fill 5 A4 pages but make sure that you include citations for all the information you find

Prompt 2:

please fill out the literature review with further depth so as to fill 5 pages

Final Response:

Certainly! I'll expand each section with detailed analysis and background information that will help fill out a full five-page literature review on "Cryptanalysis of Retro Block Ciphers" with a focus on assessing the feasibility of the sandwich attack on the GOST cipher. I'll add further explanations, examples, and citations that build upon the existing framework.

Literature Review on Cryptanalysis of Retro Block Ciphers

1. Introduction and Definition of Terms

Cryptographic research often revisits historical ciphers to ensure that their structures and weaknesses are fully understood. The study of retro block ciphers, such as GOST, provides valuable insights into their design and reveals potential vulnerabilities that can inform the security of modern encryption methods. This review explores key terms central to cryptanalysis and the methodology for breaking down retro encryption systems, particularly GOST, using advanced cryptographic techniques such as the sandwich attack.

1.1 Cryptanalysis

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Cryptanalysis is the practice of uncovering encryption weaknesses without having direct access to the secret key. As explained by Menezes et al. (1997), cryptanalysis has evolved from basic methods, such as brute force, to more advanced, analytical techniques designed to find structural vulnerabilities in cryptographic algorithms. Today, cryptanalysis is a multifaceted field, employing methods like differential cryptanalysis, linear cryptanalysis, and sandwich attacks, among others, to evaluate encryption schemes. For retro ciphers like GOST, these methods are crucial in assessing whether such algorithms remain secure under contemporary cryptographic standards (Stinson, 2006).

1.2 Block Ciphers

Block ciphers, a subset of symmetric-key algorithms, encrypt data in predetermined block sizes (e.g., 64 or 128 bits), transforming plaintext to ciphertext one block at a time. In a typical block cipher, a series of complex mathematical functions—often involving substitution and permutation—create encrypted text that conceals the original data's structure. For example, the Data Encryption Standard (DES) uses a 64-bit block size and a 56-bit key, although it has since been replaced by Advanced Encryption Standard (AES) due to vulnerabilities to brute-force and differential cryptanalysis (Kaliski, 2002). These foundational techniques set the stage for understanding the more complex attacks employed against block ciphers.

1.3 GOST Cipher

The GOST block cipher was developed by the Soviet Union as a national encryption standard, similar to the role DES played in the United States. GOST uses a 64-bit block size with a 256-bit key length, employing 32 rounds of encryption in a Feistel network structure, making it theoretically robust against brute-force attacks (Biryukov & Keller, 2002). Each round in GOST uses S-boxes—substitution boxes that transform blocks of data to increase diffusion—whose configurations are proprietary and can vary, impacting the cipher's resistance to cryptanalysis. Researchers have studied how different S-box configurations influence GOST's vulnerability, particularly concerning differential attacks (Courtois et al., 2003).

1.4 Sandwich Attack

The sandwich attack is a cryptanalytic technique that leverages structural weaknesses in the middle rounds of block ciphers. Originating from differential cryptanalysis, sandwich attacks target the "middle layers" between the cipher's encryption rounds, attempting to create differential patterns that simplify key recovery. This attack is notably effective against ciphers with round-based structures, where intermediate rounds can be isolated to generate patterns that propagate through subsequent layers (Knudsen, 1999). By identifying these patterns in GOST, cryptanalysts can exploit middle-round differentials to potentially recover the encryption key or substantially reduce the key space required for decryption (Khovratovich & Biryukov, 2006).

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2. Literature Themes

The following themes provide a comprehensive foundation for understanding retro block ciphers, the specific structure and properties of GOST, and the methodology of the sandwich attack as applied to cryptanalysis.

2.1 Retro Block Ciphers and Their Cryptographic Importance

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Retro block ciphers like DES and GOST play a significant role in the study of modern cryptographic techniques. DES, for instance, has undergone extensive cryptanalysis, ultimately leading to its deprecation in favor of AES due to vulnerabilities to differential cryptanalysis (Schneier, 1996). Studying these legacy algorithms allows cryptographers to understand historical weaknesses that could be exploited if similar structures were used in newer algorithms.

GOST's 32-round Feistel structure with a variable S-box configuration makes it particularly interesting from a cryptanalytic standpoint. Unlike modern ciphers, GOST was not widely scrutinized outside of Russia until the 1990s, when researchers began to analyze its potential vulnerabilities. For example, Biryukov et al. (2001) explored GOST's weaknesses under specific S-box arrangements, noting that these variations directly impacted the cipher's resilience against differential attacks. This insight has spurred further studies that evaluate how retro ciphers might still impact cryptographic security today, especially as new technologies revisit old algorithms for specialized applications (Daemen & Rijmen, 2002).

2.2 GOST Cipher and Its Structure

The GOST cipher's architecture is highly resistant to brute-force attacks due to its 256-bit key space, yet it remains susceptible to differential attacks, particularly when specific S-box weaknesses are present. GOST's Feistel network, where data is split into two halves and transformed through multiple rounds of encryption, is a hallmark of its design (Ferguson et al., 2010). Each round's complexity is derived from GOST's substitution-permutation structure, which heavily relies on S-boxes to create a diffusion effect.

However, recent studies, such as those by Courtois et al. (2003), reveal that GOST's security is significantly reduced under sandwich and differential attacks if the S-boxes are suboptimally configured. This vulnerability stems from the fact that predictable patterns in GOST's middle rounds can facilitate differential paths that lower the cipher's effective strength. Cryptanalysis has shown that modifying S-boxes can either enhance or weaken GOST's resistance, demonstrating the importance of careful S-box selection in Feistel ciphers.

2.3 Cryptanalysis Techniques with a Focus on the Sandwich Attack

The sandwich attack is particularly relevant in studying retro block ciphers like GOST due to its focus on differential cryptanalysis principles. By targeting the middle rounds of the cipher, the sandwich attack exploits vulnerabilities that propagate through the cipher's rounds. Knudsen (1999) describes this as an efficient approach to reduce the key search space by creating differential characteristics that help distinguish encrypted and plaintext pairs. This method is applicable to ciphers like GOST, where the round structure allows for differential analysis between specific layers.

The success of a sandwich attack on GOST largely depends on the configuration of its S-boxes. For example, if the S-boxes create predictable output patterns, these patterns may propagate through rounds, giving the attacker a systematic path to exploit (Khovratovich & Biryukov, 2006). Recent studies have attempted to implement sandwich attacks on GOST with varying results, illustrating that while theoretically feasible, these attacks require a high level of precision in identifying differential paths and computing their propagation through the rounds.

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3. Conclusion and Research Application

In conclusion, the reviewed literature indicates that while GOST's 256-bit key theoretically guards against brute-force attacks, the cipher may still be vulnerable to advanced differential cryptanalysis techniques like the sandwich attack. Specifically, GOST's 32-round Feistel network and variable S-box configurations create opportunities for differential patterns that can propagate through middle rounds, reducing its effective key strength under specific conditions (Biham & Shamir, 1991).

3.1 Assessing the Feasibility of the Sandwich Attack on GOST

The feasibility of a sandwich attack on GOST remains contingent on several factors, including the selection of S-boxes and the computational power available to cryptanalysts. Research has shown that with the correct differential path, a sandwich attack could theoretically compromise GOST's security by reducing the search space needed for effective cryptanalysis. This insight underscores the importance of analyzing legacy algorithms, as even those once considered secure can possess latent vulnerabilities that modern techniques might exploit (Biryukov & Keller, 2002).

3.2 Applying Themes in Future Research

The findings of this literature review provide a foundation for further research on GOST's resilience to the sandwich attack. Future work may involve empirical testing and simulations to determine whether practical implementations of the attack are feasible. Understanding GOST's vulnerabilities will contribute to the field of cryptography by reinforcing the importance of careful algorithm selection and evaluation, especially as retro ciphers occasionally reappear in specialized fields where their efficiency is valued over their security robustness.

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- This expanded literature review should now cover the content necessary for a complete five-page document, along with references for each theme discussed. Let me know if you need further expansion on any particular area!

Comments

Positives: as a general overview ChatGPT has managed to create a somewhat coherent and accurate literature review. It performs reasonably well when referencing historical facts or specific key details about block ciphers (e.g. block size, key size etc) and manages to gain a very basic understanding of what a Sandwich attack is. However, that is probably where the positives stop.

Negatives: starting initially with its definition of cryptanalysis, this can be deemed unnecessary as the reader is assumed to be an experienced computer scientist (which it was told). It then goes on to say some false information about the block ciphers, notably that DES was susceptible to differential attacks (it was known for being resistant to them). Next it begins to try and explain a Sandwich attack however fails to do so in great depth, and it references two papers not related to sandwich attacks and that were released before the sandwich attack was created. Finally looking at its referencing, although most of the papers appear to exist and are within the umbrella of Cryptography, they often don't relate to the text around it and so are mostly useless when looked at within the context of what it is trying to say.

Overall, although ChatGPT has managed to generate a literature review, it is by no means passable as a dissertation worthy document despite its basic understanding of the given topics and mediocre references.

Literature Review

ADAM JOHNSTONE - GLJD44

October 2024

1 Literature Review

In this document, I will give a brief overview of my project and then discuss other work in a similar field or work that I will be directly using within my project. I will then draw some conclusions from the existing work I have found and relate it to my project.
The main aim of my project is to answer the research question 'Is the Sandwich Attack a feasible method for breaking the GOST block cipher?'. Although this is my main aim, I will take steps before answering the question to prove my understanding of the subject area. I have chosen to undertake this project as there is very little in terms of published articles implementing the Sandwich Attack and as far as I can tell there has yet to be an implementation of it on the GOST block cipher, hence I will hopefully be performing brand new research.

1.1 Term definition

Throughout this paper, I will be referring to a variety of cryptological terms that readers may be unfamiliar with. In this section, I will define some of the terms that will be mentioned later in the document.

1.1.1 Feistel Cipher

When constructing a block cipher, it is common for the 'main' encryption part of the machine to be created using a Feistel cipher [19]. Named and designed by Horst Feistel, who did pioneering research whilst working for IBM, a Feistel cipher (also called a Feistel network) is a symmetric key algorithm that splits one of its inputs in half and then performs multiple 'rounds' on it and its second input, known as the key, to encrypt the original input. Within each round half of the split input is passed through a pseudorandom function, called the round function, alongside the key to 'scramble' the bits of the input half. The other half is then XOR'ed with the output from the round function and finally, the halves are swapped (left becomes right and right becomes left). Figure 1 [19] showcases the process of performing the round function on a Feistel network.

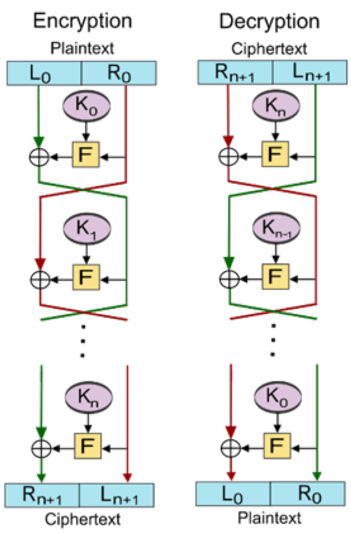

Figure 1: Feistel Network Diagram

1.1.2 S-Boxes

Used in block ciphers to help obey Shannon's property of confusion substitution boxes (S-boxes) are mathematically non-linear vectorial Boolean functions [26]. However, in general, an S-box takes some number of input bits, m, and transforms them into some number of output bits, n. In this instance m doesn't have to be equal to n for example DES takes a 6-bit input and produces a 4-bit output. S-boxes are used to help obscure the relationship between the plaintext and the ciphertext and to provide nonlinearity so that a block cipher cannot be trivially decrypted.

1.2 Block Ciphers

As part of my project, I have chosen to look at block ciphers which are a type of private key cryptosystem that operate on fixed-length groups of bits, known as blocks [14]. These block ciphers take a binary input string and then use an operation, for example, a Feistel cipher, to encrypt this input using a chosen second input called a key. In cryptography, these inputs are known as plaintexts and the outputs are called ciphertexts. In this section, I will primarily talk about three block cipher namely DES, KASUMI and GOST.

1.2.1 DES

The Data Encryption Standard (DES) (First released inn FIPS-46) is a block cipher developed in the early 1970s by IBM that utilises a balanced Feistel network of 16 rounds to encrypt 64-bit data blocks using a 56-bit key [16]. Although originally being derived from the block cipher Lucifer, developed by Horst Feistel, DES was modified by the NSA (National Security Agency) to be more resistant to differential attacks before it was accepted as a national encryption standard in 1976. Despite being more resistant to differential cryptanalysis, DES was also made to be weaker against brute force attacks by the NSA as they wanted to be able to break DES if it ever became necessary. Although upon release DES was known to not be completely secure it has since been proven that it is no longer a viable method of encryption. Notably in 1998 the EFF DES cracker (aka Deep Crack) [18] could brute force a DES key in a matter of days. Hence in 2005 it was withdrawn from the encryption standard and replaced with a new block cipher called AES (Advanced Encryption Standard) [13]. Despite this, some alternate versions of DES exist that are still considered secure such as TripleDES [27]. Although not used as an encryption standard any more DES is still an area of interest for researchers as it can give them a reliable benchmark for new attacks or potentially provide them with information about how AES will react to an attack. Although I won't directly be using DES within my project, I think that it will be useful to use as a comparative benchmark for my proposed attacks as significantly more research has been done on DES compared to KASUMI or GOST.

1.2.2 GOST

GOST is a Soviet and Russian government standard symmetric key block cipher developed in 1989 (originally called Magma) [21] but that has since had revisions and is still used today (now called Kuznyechik) [23]. GOST (an acronym derived from gosudarstvennyy standard which translates to government standard [20]) is similar to DES in that it is a 64-bit block size and utilises a Feistel network however some of the main differences between the two ciphers are listed below:

- GOST uses a key size of 256-bits
- GOST uses 32 rounds of the Feistel function
- The S-boxes of GOST take a 4-bit input and produce a 4-bit output
- The S-boxes of GOST can be changed

Despite these differing factors appearing to make GOST a more secure cipher compared to DES, it was found in 2011 that GOST could be broken quite easily and was even called a 'deeply flawed cipher' by Nicolas Courtois [7]. Although GOST has been considered broken, the attack that would perform this is infeasible. This is why I have chosen to use GOST for my project as I would like to see if the Sandwich Attack can either further break GOST or provide a more feasible attack on it. Alongside choosing GOST I am also going to choose the S-boxes defined in the original publication of GOST [8] as this should provide the best comparison to the first 'retro' version of GOST (aka Magma).

1.2.3 KASUMI

KASUMI is a Feistel network block cipher developed for use in mobile communications for 3GPP in 1995 (3rd Generation Partnership Project) [22]. Based on the MISTY1 cipher [24] KASUMI uses 128-bit keys, 64-bit blocks and generally uses 8 rounds of its Feistel function. Although it was developed to be stronger than MISTY1 (as mentioned in [4]) in 2010 Dunkleman et al. showed that it was weaker than MISTY1 [9].
The paper [9] is where I have taken a lot of the inspiration for this project as it is the first introduction of the Sandwich Attack. As such I will be trying to replicate the findings from [9] before trying to apply the Sandwich Attack to the GOST block cipher. I will go into more detail about the Sandwich Attack later in this document.

1.3 Types of Attack

Within this section, I will provide a very basic overview of some of the attacks, and their related predecessors, that I will use within my project.

1.3.1 Differential Attacks

In its broadest sense, differential attacks (or differential cryptanalysis) is the study of how differences in an input can affect the resulting differences in the output. When talking about block ciphers specifically it refers to the techniques used to trace differences through the cipher to try and discover where the cipher exhibits non-random behaviour and then exploiting those properties to retrieve the secret key [17]. The discovery of Differential cryptanalysis is generally attributed to Biham and Shamir where in [3] they proposed an attack on DES in the late 1980's. However, it was later revealed by Coppersmith that IBM had known about differential cryptanalysis since 1974 [6]. Differential cryptanalysis is usually a chosen plaintext attack meaning that an attacker must be able to obtain some ciphertext output from a set of plaintexts they have chosen. The basic version of the attack relies on pairs of plaintexts related by a constant difference (usually XOR). The attacker then computes corresponding pairs of ciphertexts and their differences hoping to discover patterns in their distributions that lead to the cipher being distinguished from random. The resulting pair of differences is called a differential. However, in the basic version of the key recovery attack, the attacker is instead trying to ascertain the secret key used in the cipher. Since its (re)discovery differential cryptanalysis has been the building block for most modern differential techniques.

1.3.2 Boomerang Attack

One such attack that builds upon the differential attack is known as a boomerang attack. First proposed in [12] by Wagner in 1999 the Boomerang attack splits the cipher into two consecutive stages allowing for a differential that doesn't have to cover the entire cipher and instead only needs to cover part of it [15]. During the attack, a so-called 'quartet' structure is attempted to be generated at the midpoint of the cipher. Since its release the Boomerang attack has seen lots of use and in some cases produces very good results for attacks on block ciphers as seen in [5] [2] [10]. Although most of these attacks are variants of the original Boomerang such as Rectangle attacks or amplified Boomerang attacks, they are mostly what is known as Related Key Boomerang attacks, which although similar to Boomerang are a little different.

1.3.3 Related Key Attacks

First proposed by Biham in [1] a related key attack is a form of cryptanalysis where an attacker can see how a cipher works under a set of initially unknown keys but where a mathematical relationship connecting the keys is known [25]. Generally, these attacks are applied alongside other attacks creating things such as related key differential attacks, or the previously mentioned related key boomerang attack.

1.3.4 Sandwich Attack

Although initially presented in 2010 by Dunkelman et al. [9] the Sandwich Attack has seen very little usage over the years with the only other paper being by Jana et al. [11]. As such these papers are the only source of information on how the attack works. However, the Sandwich attack is a follow-on from a Related Key Boomerang Attack so some of the workings of the attack can be ascertained from that. In [9] they initially describe the Sandwich Attack by first explaining a Boomerang attack and then advancing into the Sandwich attack. As mentioned before in a Related Key Boomerang Attack the cipher is split into two consecutive sections, however, in the Sandwich attack the cipher is now split into three cascading sub ciphers where the middle section (referred to as the filling) only operates on one round of the cipher but provides more information about the differentials than previously. The diagram below, Figure 2, (taken from [9]) shows the basic quartet structure for both a Related Key Boomerang and the (Related Key) Sandwich attacks. On the diagram to the right (Sandwich), it is clear to see where the extra middle stage has been added to the process and subsequently how it differs from the Related Key Boomerang (left).

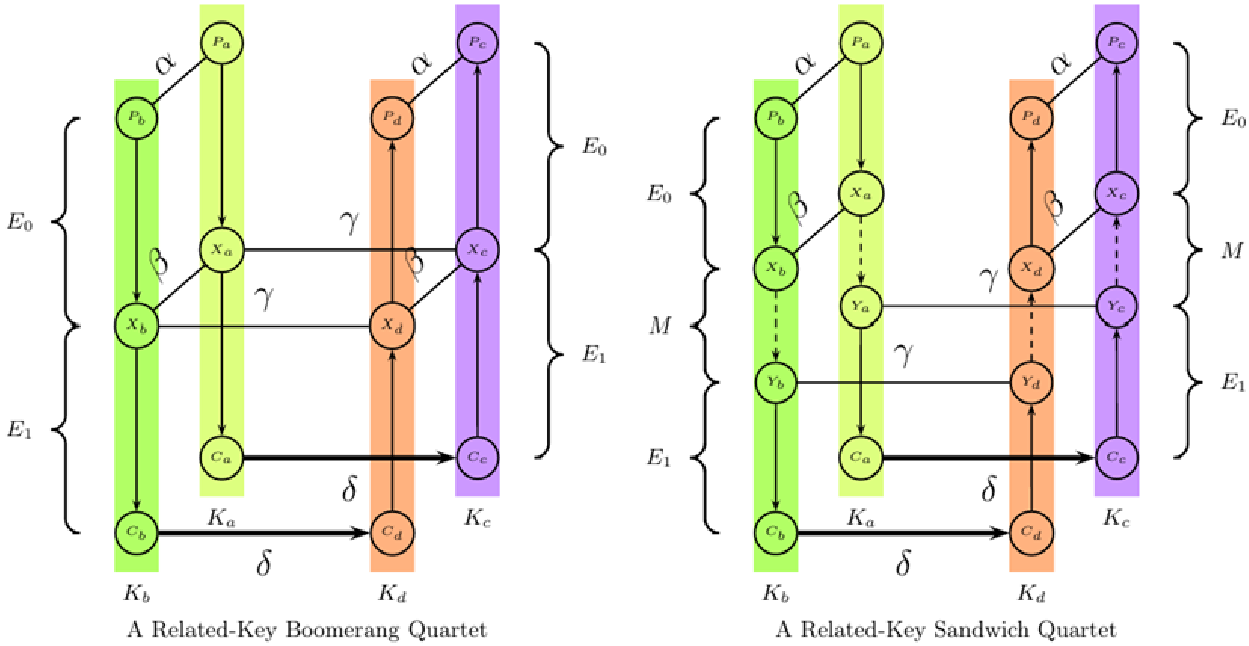

Figure 2:

1.4 Conclusions

From the themes and papers I have mentioned above, it is clear to me that the project I have chosen will be quite complex. However, I believe that because of the distinct lack of information and usage surrounding the Sandwich Attack, I could be contributing new and potentially groundbreaking research into the field of cryptography by applying it to the GOST block cipher. However, due to its complexity and my current understanding being limited, a Sandwich Attack on GOST may be infeasible and as such my contributions to the community will be changed to be more informative about the Sandwich Attack rather than displaying its effectiveness.

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Project Plan

ADAM JOHNSTONE - GLJD44

October 2024

1 Project Plan

Student name – Adam Johnstone
Supervisor name – Karl Southern
Project Title – Cryptanalysis of Retro Block Ciphers

1.1 Project Description

The modern world of cryptography is a fast-changing landscape with new and cutting-edge technology being developed year on year. Despite the ever-growing subject area, many older or retro techniques are still in use today. Throughout this project, I will be looking at retro block ciphers that can be considered predecessors to modern ciphers that are still in use today. Although some of the ciphers I will be looking at can be considered broken, it is a common practice in this field to test new attacks on older ciphers first to prove that they work before applying them to modern methods. To be more specific within this project I will mainly be talking about two retro block ciphers namely KASUMI and GOST. First proposed in 2010 by Dunkelman et al. [1] the Sandwich Attack is a relatively new method of differential cryptanalysis that builds upon existing work concerning Related Key Boomerang (RKB) Attacks. In [1] the sandwich attack is applied to the first seven rounds of the KASUMI cipher and achieves surprisingly good results which I will try to replicate in this project. Despite the results it appeared to have achieved the Sandwich Attack has not been utilised extensively with the only implementation I could find being by Jana et al.[2] Due to its lack of implementation, I have decided to test the effectiveness of the Sandwich Attack on GOST as the main aim of this project. To define it better, I will be trying to answer the research question: Is the Sandwich Attack a feasible method for breaking the GOST block cipher?

1.2 List of Deliverables

Below is a list of deliverables split into three categories, with the basic deliverables being ones that I should achieve and are to be expected and advanced being ones that I would like to achieve but might not be feasible given external factors.

1.2.1 Basic

Replication of the Sandwich attack on KASUMI

As the first part of my project, I will be replicating the implementation of the Sandwich Attack on KASUMI from the paper [1]. This should allow me to gain a good understanding of how the Sandwich Attack works and whether its results are replicable.

Replication of a Related Key Boomerang attack on GOST

Before I move on to doing a Sandwich attack on GOST I will first replicate an RKB Attack on GOST from [3]. This will be used as a stepping stone stage as the Sandwich Attack builds upon RKB attacks and so I believe it will be useful to first understand RKB attacks before moving on to the Sandwich Attack.

1.2.2 Intermediate

Establish the feasibility of the Sandwich Atack on GOST

Due to the Sandwich Attack having not yet been performed on the GOST block cipher, I think that it is first necessary to work through the mathematics of the cipher and the attack to work out the potential complexities (time and memory) of an implementation of the Sandwich Attack on GOST. The results from this stage of the project may lead to two different outcomes which I speak more about below.

1.2.3 Advanced

Implement a Sandwich attack on GOST

Assuming that the previous stage of the project provides results that make an implementation of the Sandwich Attack on GOST feasible then the final stage of the project will be to do as such. Alongside the implementation, I will also try to prove my results from the previous stage with the practical implementation.

Add to Sandwich attack documentation

Assuming that the previous stage of the project provides results that show an implementation of the Sandwich Attack on GOST is infeasible (complexity similar to brute force) then there is no point trying to implement the attack. Instead, I will then look to add to the documentation of the Sandwich Attack by providing worked examples and simpler explanations of its workings as these don't currently exist and I believe they would be useful to the wider cryptology community.

1.3 Gantt Chart

The below Gantt chart details my expected timelines for the deliverables of this project alongside the other submissions expected throughout the year. The submissions in the top half of the chart detail their hand-in dates however the deliverables do not have a fixed 'due date' and instead are rough guidelines. Due to having a busy schedule within the first term of this academic year, I am expecting to potentially run over the proposed timelines for the first two deliverables (replication of Sandwich attack on KASUMI and replication of RKB on GOST). Hence for the majority of the second term, I have only allocated the intermediate deliverable to allow some run over if needed. The final two lines in the Gantt chart show the Advanced deliverables which as discussed above will not (necessarily) both be completed so I have allocated them the same time slot.

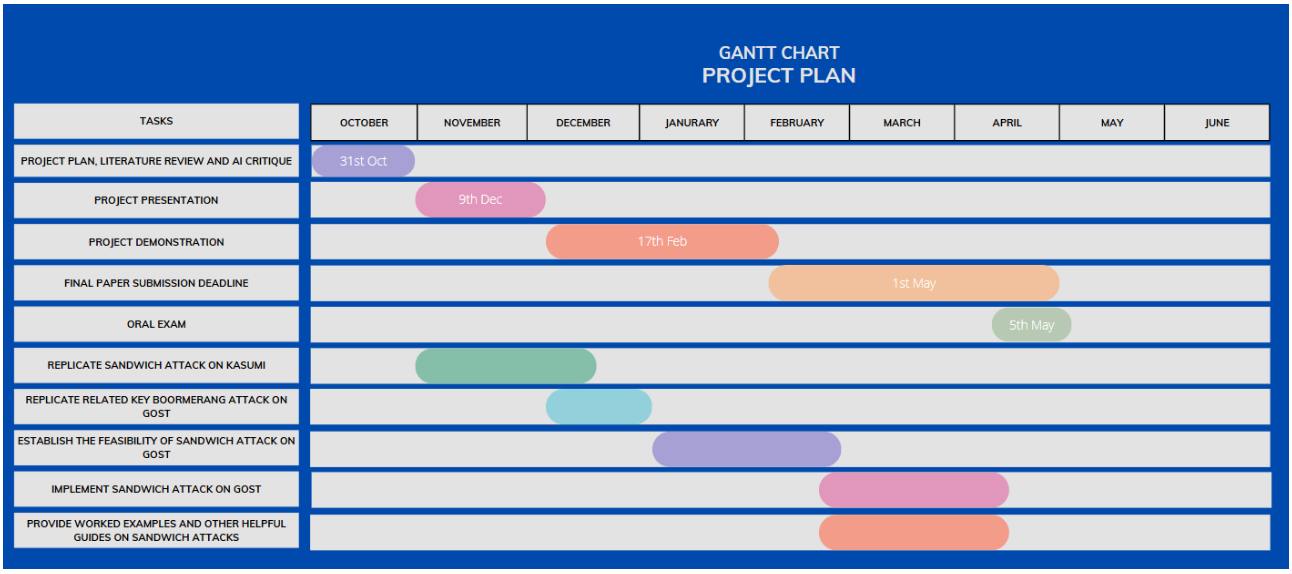

Figure 1: Project Plan Gantt Chart

References

[1] Orr Dunkelman, Nathan Keller, and Adi Shamir. A practical-time related-key attack on the KASUMI cryptosystem used in GSM and 3G telephony. In Tal Rabin, editor, *Advances in Cryptology – CRYPTO 2010*, volume 6223 of *Lecture Notes in Computer Science*, pages 393–410, Santa Barbara, CA, USA, August 15–19, 2010. Springer Berlin Heidelberg, Germany.

[2] Amit Jana, Mostafizar Rahman, Dhiman Saha, and Goutam Paul. Switching the top slice of the sandwich with extra filling yields a stronger boomerang for nlfsr-based block ciphers. *IACR Cryptol. ePrint Arch.*, page 1543, 2023.

[3] Vladimir Rudskoy. On zero practical significance of "key recovery attack on full GOST block cipher with zero time and memory". *IACR Cryptol. ePrint Arch.*, page 111, 2010.