SLIM: A Lightweight Block Cipher for Internet of Health Things

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ABSTRACT  Nowadays, there is a strong demand for increasing the protection of resource-constrained devices such as Radio frequency identification (RFID) systems. Current cryptographic algorithms are sufficient for high-resource desktop computers. RFID systems are commonly used in high-security applications such as access control systems, transaction banking systems, and payment systems. The attacker attempts to mislead RFIDs for unauthorized access to services without payment or to circumvent security mechanisms by detecting a secret password. The biggest challenge in RFID systems is how to ensure successful protection against such infringements. Lightweight cryptography can provide security assurance for protecting RFID systems. This article presents a new ultra-lightweight cryptography algorithm for RFID systems called SLIM. SLIM is a 32-bit block cipher based on the Feistel structure since block ciphers are the most used cryptographic and provide very tight protection for IoT devices. The key challenge in designing a lightweight block cipher is to cope with performance, cost, and security. SLIM, like all symmetric block cipher, uses the same key for encryption and decryption. The proposed algorithm has an excellent performance in both hardware and software environments, with a limited implementation area, an acceptable cost/security for RFID systems, and an energy-efficient behaviour. SLIM has demonstrated high immunity against the most effective linear and differential cryptanalysis attacks and has a sufficient margin of defence against these attacks.

INDEX TERMS  RFID, block ciphers, lightweight cryptography, feistel ciphers, cryptanalysis.

I. INTRODUCTION  Saving human life is considered the most important demands in the world. Therefore, the real-time healthcare monitoring system of patients’ physical conditions is one of the significant requirements of hospital authorities. Remote Patient Monitoring System (RPMS) plays an important role in today’s healthcare system and it uses different technologies, mainly IoHT, where it allows storing patient’s data on the cloud. Generally, in a smart healthcare system, sensing devices for biomedical instrumentation transfer medical data of patients to a Central healthcare server Control Room (CCR) in normal cases. In the critical case, medical data is transferred remotely to the doctor using the Global System for Mobile Communication (GSM) module. The carried personal medical data may be moved through an untrusted network or may be stored in an untrusted cloud service, confidentiality of sensitive data will be exposed to cyber-attacks. Moreover, a vital issue must be considered when it transfers through resource constrained IoHT devices. Traditional algorithms aren’t suitable for the nature of these devices. Existing cryptographic algorithms are mainly suitable and designed for the desktop computing era. In today’s era, tiny computing devices are much popular, but on the other hand, these resource-constrained devices bring security risks. Standard cryptographic algorithms are not well suited for very
constrained software and hardware devices such as RFID systems. RFID systems (see Figure 1) consist of three main components; RFID tag, reader, and back-end database (server). RFID systems have several real applications in healthcare such as patient identification and tracking, equipment and asset tracking, reducing blood and drug administration errors, etc. Apart from this it has several other applications in real life such as contactless payments, electronic passports, product tracking, etc. An RFID tag is added to these products that contain important information about the product. The RFID tag or transponder is an identification technology that consists of an integrated circuit (IC) connected to an antenna. The integrated circuit is used for computation and storage purposes. The antenna provides communication between the transponder and the reader. Due to their low production costs, they can be attached to any object in the surroundings. An RFID tag can be classified based on the source of power into three categories, active tag, passive tag, and semi-passive tag. Active tags have a power source that could be a battery through which the internal circuit and antenna get the power. Passive tags do not contain any power source, and the RFID reader or transceiver provides energy for the RFID tags. There are now several different commercially available passive RFID transponders. Semi-Active tags have a battery, but that provides power only to the internal circuit, and this power is not used by the antenna. Each tag can also be divided into two types: Read-Write tags and Read-only tags. Read-write tags allow to store information as well as to modify them while on the other hand, Read-only tags allow only to read the saved information. The RFID system can be seen as the future of the barcode and soon will replace the barcode. In the context of this article, passive RFID tags are important because passive tags have very limited memory, power, and computing capability and therefore applying standard cryptographic algorithms is not feasible.

This article proposes a new ultra-lightweight cryptographic algorithm suitable for RFID restricted tags. The proposed algorithm is intended to protect the RFID data as well as the transmission. With simple operations on the RFID tag, it will be enabled to defend against different types of attacks, which make it very attractive to low-cost RFID. The most widely used cryptographic primitive is block cipher nowadays that provides very tight security to IoHT devices and can be applied to encryption, hashing, authentication, and random bit generations. A block cipher has versatile primitives, and a stream cipher can be achieved by running block cipher in counter mode. Also, it is easy to understand the block cipher design rather than the stream cipher. The biggest challenge to design lightweight block cipher is to cope with trade-offs between performance, cost, and security. This is not possible to provide all these three properties together to resource-constrained devices. The cipher in this article is designed carefully with respect to power and area constraints and tried to avoid any compromise with security. The cipher has the following properties:

- SLIM is a symmetric block cipher that is based on the Feistel structure. This implies that the same key is used for encryption as well as decryption.
- SLIM uses four $4 \times 4$ S-boxes that works as a non-linear component of the cipher and perform a non-linear operation on a 16-bit word.
- SLIM has very simple implementation and design, however; it has a rigidity profile against the most effective malicious cryptanalyses “linear and differential attacks”.
- The cipher can be easily implemented with resource-constrained devices such as RFID and suitable for the Internet of Health Things.

The paper is organized as follows: Section II presents the literature review and the contemporary lightweight cryptographic algorithms. The proposed algorithm architecture and its functions are discussed in Section III. Implementation considerations of the SLIM algorithm are given in Section IV. The performance evaluation is discussed in Section V. The performance evaluation is discussed in Section VI presents the cryptanalysis results against linear and differential cryptanalysis and shows that cipher has enough security margin against these two powerful attacks. Finally, the paper ended with a conclusion and references.

II. RELATED WORK

In RFID devices, the storage area available for the cryptographic feature is restricted, and allowable power consumption is severely constrained. Therefore, one of the most suitable solutions for information protection in these environments is the lightweight cryptographic algorithm. This section discusses the most current state of the art in lightweight primitives or algorithms that are designed to meet the limitations of low-cost RFID. Consequently; studying block ciphers, stream ciphers, hash functions, and random number generators.

RFID systems suffer from several malicious attacks. The risks are evolving too [24] by developing RFID technology day by day. Considering the nature of RFID Tags, it is important to implement different cryptographic protocols to reduce the impact of security and privacy issues. Modern encryption algorithms designed for high-end devices are not suitable for RFID tags because the implementation of these schemes would require ample computational power, memory, and resources [25].

Block ciphers are one of the most fundamental cryptographic primitives. The first lightweight block ciphers go
back to 1997 by the appearance of the TEA block cipher [26]. Table 1 shows a comparison between some of the recent proposals for lightweight block ciphers concerning their specifications. Ciphers are compared concerning the hardware implementation area required in gate equivalent (GE), their speed in Kbps at the frequency of 100 kHz, and their CMOS technology in $\mu$m. The list includes two standard lightweight block ciphers, PRESENT [2] and CLEFIA [10].

The use of hash functions is also common in proposals for RFID systems regarding security and privacy protocols. Some of the recent lightweight hash functions and their specifications are compared in Table 2. It should be noted that the algorithms listed in the table may have different variants regarding block size, output size, or internal state size, but as a representative, only one of the variants is mentioned. There are not many proposals for lightweight stream ciphers comparing to block ciphers. Table 3 displays some of the recent proposals for lightweight stream ciphers, Grain v1 [23], Trivium [23], Enocoro [22]. The most popular of these are two hardware-oriented ciphers listed in the portfolio of the eStream project, Grain v1, and Trivium. However, the Enocoro and Trivium algorithms are the standard lightweight stream ciphers.

### III. STRUCTURE OF THE PROPOSED ALGORITHM

This section presents the structure of the proposed algorithm (SLIM). It is a symmetric encryption algorithm in which both the encryption and decryption processes use the same
key (encryption and decryption keys are identical). The only
difference between the two processes is that the decryption
sub-keys are applied in reverse order. In SLIM, two essen-
tial design issues are taken into consideration, security, and
simplicity. It achieves immunity against the exhaustive search
attack by using the NIST recommendations report for key
length (key length $\geq 80$). SLIM accomplishes both confusion
and diffusion concepts. A compact 4-bit S-box with high non-
linearity properties are used to fulfil confusion. A combina-
tion of operations besides the nature of the Feistel structure
is used to diffuse the data. On the other hand, simplicity is
achieved in terms of the compact size of the S-box as well
as the used internal simple operations. SLIM block cipher
operates with 32-bit plaintext and ciphertext blocks and is
controlled by an 80-bit key. The fundamental feature in the
design of this algorithm is to have the smallest footprint area
suitable for RFID applications. The cryptosystem structure
was designed to be easily implemented in both software and
hardware. Besides, SLIM consists of 32 rounds using 32 sub-
keys each of 16-bit that are generated from the 80-bit key. The
Basic architecture of the SLIM encryption algorithm is shown
in Figure 2. As can be seen in this figure, SLIM architecture
is based on a Feistel structure. The input is divided into right
and left parts that go through several rounds (32-round) along
with the generated sub-keys. The input could be 32-bits as
well as the key size is 80-bits.

A. SINGLE ROUND PROCESSING

The more detailed architecture of SLIM can be obtained by
investigating the internal structure of a single round. The first
thing is that the 32-bit input is divided into two equal sixteen-
bite halves known as $L_i$ and $R_i$. The overall processing at each
round can be summarized by Equation 1 and 2 where the
right half of the input $R_i$ and the sub-key $K_i$ are manipulated
using XOR operation. The output of the XORing operation is
forwarded to a substitution box and the output of the S-boxes
is forwarded to a permutation process. Finally, the output is
XORED with the left half to become the right half input of the
next round. The right half of the input $R_i$ became the left half
input of the next round, see Equations 1 and 2.

\begin{align*}
L_i &= R_{i-1} \\
R_i &= L_{i-1} \oplus P(S(K_i \oplus R_{i-1}))
\end{align*}

SLIM has been designed to mitigate the previous work
limitations and their constraints such as S-boxes trapdoors,
memory space, speed, lookup tables, P-boxes, key size, com-
plexity, software, and hardware implementations.

B. SUBSTITUTION LAYER

S-boxes design is one of the most challenging tasks in cryp-
tography. They can be considered the cornerstone of all cryp-
tosystems because they are the only non-linear component
in the most modern algorithms. Therefore, the feeble design
of S-boxes produces a weakness in the overall algorithm.
Biham introduced the differential cryptanalysis in 1991 [27],

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{SLIM_encryption}
\caption{SLIM encryption.}
\end{figure}
footprints of 4-bit S-boxes [2]. Substitution layer is chosen based on linear and differential cryptanalysis performed on cipher.

**C. PERMUTATION LAYER**

In general, the permutation is a rearrangement process. Here, the permutation is the last phase of the SLIM function. The permutation box accepts 16-bit and permutes them using a certain rule producing a 16-bit output. In Table 5, the permutation process is given considering that there is no fixed point to avoid linearity analysis. Permutation layer is chosen based on linear and differential cryptanalysis performed on cipher.

**D. KEY GENERATION**

For 32 rounds and a block of 32-bit, it is required 32 sub-keys (16-bit), which are generated from the 80-bit encryption key (see Figure 3). The scheme for generation is as follows:

- The first five sub-keys, labelled $K_1$, $K_2$, ..., and $K_5$ are taken directly from the original key, with $K_1$ is equal to the first (least significant) 16-bits, $K_2$ corresponding to the next 16-bits, and so on. Then, the 80-bit key passes through a divider those results in two 40-bit quantities, labelled KeyMSB and KeyLSB; each half is thereafter treated separately.
- At each round, KeyLSB goes through a circular left shift by two bits, and then the produced output is XORed by the KeyMSB. The output of the XORing operation is forwarded to a substitution layer. The output of the S-boxes and the rotated KeyMSB (KeyMSB ≤ 3) are manipulated using XOR operation to produce the round sub-key.

**E. SLIM DECRYPTION STRUCTURE**

The process of decryption is the same as that of encryption. SLIM decryption is done using ciphertext as an input to the same SLIM structure, but the decryption sub-key is applied in the reverse order with another selection of sub-key. The reverse process can be seen in Figure 4 for both encryption and decryption of round $i$. The decryption round structure is similar to that of encryption, like any symmetric encryption algorithm. In Figure 4 the left-hand side shows the encryption process with the $K_i$ subkey. The round output consists of n-bits representing the coded message. On the other hand, the decryption procedure with the same sub-key $K_i$ is shown on the right side of Figure 4. The round function is in the opposite order. The round output is made of n-bits representing the original message.

**IV. IMPLEMENTATION CONSIDERATIONS OF THE PROPOSED SLIM ALGORITHM**

As shown before, SLIM is designed to facilitate both software and hardware implementation. Hardware implementation achieves high speed while the software has lower cost of implementation and more flexible with several platforms. The software implementation design principles are outlined as follows:

- **Utilization of sub-blocks:** For perfect cipher operations, they have to operate on sub-blocks that are suitable and nature for software in the form of 4, 8, 16, or 32-bits. SLIM can achieve that easily because it can be adapted to use 4 or 16-bit sub-blocks.
- **Use simple operations:** Cipher operations should be easily programmed using addition, subtraction, shifting, complement, XORing, and so on. The elements of SLIM meet this requirement as well.

The design principles are also stated for hardware implementation as follow:

- **The similarity of encryption and decryption:** Encryption and decryption should only be different in the way that the key is used to enable the same device to use both encryption and decryption. SLIM has a structure that satisfies this requirement.
- **Using compact S-boxes:** it can save the memory space and the implementation costs. SLIM uses four $4 \times 4$ S-box.
- **Regular structure:** A regular structure for VLSI implementation should be in place for the cipher. SLIM is constructed based on only one simple modular building block that is repeated multiple times.
A. HARDWARE IMPLEMENTATION OF THE PROPOSED SLIM ALGORITHM

A round-based implementation of SLIM can be done straightforwardly, while a serialized implementation poses some challenges for a hardware designer. Thus, spare the details of the former architecture and focus on the latter with a data path width of 4 bits. Most challenging is the permutation step since it permutes the whole state. Thus, it is not possible to operate on 4-bit chunks, but instead, the operation on the whole state (16-bit) had been used. In the proposed architecture illustrated in Figure 5, it takes 4 clock cycles to process all chunks of the state and to perform one round of SLIM. Then swapping the content of the registers as it is required by the Feistel structure within one clock cycle, i.e. operating on the whole state. This clock cycle had been used to perform the permutation process, but in the proposed architecture, both halves of the state had been already XORed. Thus, permuting the right half in the previous clock cycles inversely before storing it as the new left half. Then when the XOR sum of both halves is permuted, the final step of one round of SLIM is performed. In short, the following operations are carried out when the content of the registers is swapped:

- **Add Round Key**: In SLIM, the key addition procedure is a 4-bit XOR operation used to achieve this mixing process, which requires about (7.5 GE).
- **Substitution-layer**: In SLIM, the non-linear S-box layer in the serial implementation consists of a single 4-bit S-box which requires about (27 GE).
- **Diffusion-layer**: At the end of each SLIM round function, a permutation process is executed, which can be implemented by simple wiring and costs no area.

Finally, the additional modulo 2 of both halves requires a 4-bit XOR operation, which requires (7.5 GE). Besides, the standard round of SLIM requires two a 2-to-1 MUXes to select between the input data (plaintext) and to let the registers latch onto the result that appears at the bottom of the data-path of the previous round; a single 2-to-1 MUX cost 2.25 GE. Consequently, the multiplexing (selecting) process requires \((2 \times 2.25 = 4.5 \text{ GE})\). Therefore, Table 6 gives the entire encryption process area in gate equivalents.

The architecture of key scheduling is shown in Figure 6. For the key generator structure, it consists of the following three sub-functions (XOR, S-box, and shifting).

- **Shifting Process**: In SLIM, the right-hand side (LSBs) of the key segments is passed through the left circular shifting process by 2 steps, which not requires any gates. The left-hand side (MSBs) of the key segments is passed through the left circular shifting process by 3 steps, which not requires any gates as well.
- **Substitution-layer**: In SLIM, Single S-box is used for key scheduling to reduce the overhead in the implementation of the datapath. The non-linear S-box layer
TABLE 6. The area estimation of the hardware implementation of SLIM in GE.

<table>
<thead>
<tr>
<th>Component</th>
<th>Gate Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registers</td>
<td></td>
</tr>
<tr>
<td>Left Shift Register (16-bit)</td>
<td>$16 \times 4.25 = 68$ GE</td>
</tr>
<tr>
<td>Right Shift Register (16-bit)</td>
<td>$16 \times 4.25 = 68$ GE</td>
</tr>
<tr>
<td>Round Function</td>
<td></td>
</tr>
<tr>
<td>XOR</td>
<td>$2 \times 7.5 = 15$ GE</td>
</tr>
<tr>
<td>MUX</td>
<td>$2 \times 2.25 = 4.5$ GE</td>
</tr>
<tr>
<td>Substitution Layer</td>
<td>27 GE</td>
</tr>
<tr>
<td>Total</td>
<td>182.5 GE</td>
</tr>
</tbody>
</table>

FIGURE 6. Key scheduling architecture of SLIM.

consists of a single 4-bit S-box (4-AND, 4-XOR), which requires about (13 GE) as shown in Figure 7.

- **XORing Process:** In SLIM, the key generator requires two 4-bit XOR operation used to manipulate the different inputs, which requires about $(2 \times 7.5 = 13$ GE).

Finally, a single 2-to-1 MUX is required to select between the input key and the result that appears at the bottom of the data-path of the previous round; a single 2-to-1 MUX cost 2.25 GE. Consequently, GE calculations for key scheduling of this architecture for its hardware implementation are shown in Table 7.

V. ANALYSIS OF THE PROPOSED SLIM ALGORITHM

In this section, the characteristics of the SLIM related to its cryptographic strength are illustrated as follow:

- **Block length:** The block length should be long enough to deter statistical analysis. This is valid for SLIM as well, where a 32-bit block is used.

- **Key Length:** The key length should be long enough to prevent exhaustive key searches effectively. With a length 80-bits, SLIM is secure in this area far into the future.

- **Confusion:** The ciphertext in a complicated and associated way should rely on the plaintext and key. The goal is to confuse the determination of how ciphertext statistics depend on plaintext statistics. SLIM achieves this goal by using a strong 4-bit S-box.

- **Diffusion:** Each plaintext bit should affect each ciphertext bit, and each key bit should affect each ciphertext, spreading the plaintext statistical structure over several bits of ciphertext. Through SLIM, a permutation procedure is carried out in addition to interchanging each round the two halves of the plaintext. This structure takes two $(n/2)$-bits values derived from the plaintext as input and two $(n/2)$-bits sub-keys derived from the key and produces $(n/2)$-bits output. Each output bit in the first round depends on each input bit from the plaintext and each bit of the sub-keys. This basic structure is repeated m times in the algorithm.

The hardware implementation result of SLIM is shown in Table 8 with a comparison of other algorithms. The figures must be taken with cares as suggested by because they depend on the type of FF, technology, library, etc. [9]. The lightweight block ciphers implemented on 0.13µm technology have been listed. Besides, Gates/Memory Bit in the table, which denotes the size (in GE) of 1-bit memory device used for the key and states, is listed as well. SPECK32-64 has a smaller implementation area, but it use only 64 bit key.

VI. CRYPTANALYSIS OF SLIM

$$\epsilon_{1,2,3...,n} = 2^{n-1} \prod_{i=0}^{i=n} \epsilon_i$$ (3)
The most important cryptanalytic tools are linear and differential cryptanalysis. In both the cryptanalysis techniques, the attacker tries to find a linear or differential path through the various round of cipher. Finding an optimal path is the most challenging task of such attacks due to the large search space of possibilities. Dhar et al. [36] proposed a Nested search based heuristic technique to find the differential path in several block ciphers. However, applying such a method directly to any cipher is not like plug and play but requires a strong coding skill to modify cipher in the required form. Such methods can be applied to find the linear or differential path in most of the block ciphers. The code is written in python language and publicly available at GitHub [37] click here.

A. LINEAR CRYPTANALYSIS

Matsui [38] in 1993 introduced the concept of Linear cryptanalysis and since that it becomes the most powerful technique to analyse any cipher. The basic idea is to generate a linear approximation that describes the relation between plaintext (input) and ciphertext (output) bits. Such a relationship should hold with probability 0.5 (bias $\epsilon = 0$) for a secure cipher. If an attacker can find a relationship where bias $\epsilon \neq 0$, then it could be converted to some attack. To find linear paths in cipher, firstly we generate the linear approximation table of given S-box. In each round, the Nested algorithm tried to find the best bias from the approximation table and return the optimal path. Total bias is calculated using a formula introduced by Matsui [38]. We could only find the differential...
TABLE 9. Linear trails for SLIM Cipher.

<table>
<thead>
<tr>
<th>Round</th>
<th>Block1</th>
<th>Block2</th>
<th>Bias</th>
<th>Active S-box</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0x0000</td>
<td>0x8000</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0x8000</td>
<td>0x0420</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>0x0420</td>
<td>0x6000</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0x6000</td>
<td>0x8400</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0x8400</td>
<td>0x8639</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>0x8639</td>
<td>0x0e0f</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>0x0e0f</td>
<td>0x5c01</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>0x5c01</td>
<td>0xd070</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>0xd070</td>
<td>0x0005</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>0x0005</td>
<td>0x0002</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>0x0002</td>
<td>0x0040</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Total Bias: 32 21

TABLE 10. Differential trails for SLIM Cipher.

<table>
<thead>
<tr>
<th>Round</th>
<th>Block1</th>
<th>Block2</th>
<th>log₂p</th>
<th>Active S-box</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0x0000</td>
<td>0x8000</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0x8000</td>
<td>0x8001</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>0x8001</td>
<td>0x1003</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0x1003</td>
<td>0x1000</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0x1000</td>
<td>0x9002</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>0x9002</td>
<td>0x0060</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0x0060</td>
<td>0x0006</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Total Probability: 27 11

FIGURE 8. Difference propagation of plaintext pair.

B. DIFFERENTIAL CRYPTANALYSIS

Differential cryptanalysis is one of the most powerful tools to analyse any cipher that was introduced by Biham and Shamir [27]. Differential cryptanalysis works in a chosen plaintext-ciphertext scenario where an intruder can access the encrypted text after selecting any plaintext as input to the cipher. To do the differential cryptanalysis, the attacker can take a pair of plaintexts, and these two plaintexts are related to each other by a constant difference. This difference could be 2ⁿ modular addition or XOR operation (see Figure 8).

A differential path (also trail or characteristic) is a sequence of differences through several rounds of cipher encryption. When searching for the differential path, attackers mainly care about non-linear components (S-box in this case). There could be many output differences (through S-box) for a particular input difference. Therefore, the attacker creates a difference distribution table of S-box that gives the probability of certain output over an output. In this article, to find a differential path in SLIM, we used the Nested tree search heuristic approach proposed by Dwivedi and Srivastava [39] and Dwivedi [40]. Firstly, we draw a difference distribution table based on S-box specifications and using that table we tried to generate a differential path. We could only find the differential path (see Table 10) up to 7 rounds and therefore cipher is secured for the full number of rounds.

VII. CONCLUSION

This article proposed a new ultra-lightweight cryptography algorithm for RFID systems called SLIM. RFID systems are suffering from a variety of malicious attacks. The key challenge in RFID systems is how to ensure successful defense against these attacks. Modern encryption algorithms designed for high-end devices are not appropriate for RFID systems, because the implementation of these schemes will require high computational power, memory, and resources. The usable cryptographic storage area is limited in RFID systems and the permissible power consumption is severely constrained. Lightweight cryptographic algorithms are one of the most appropriate solutions for securing information in these environments. The proposed ultra-lightweight cryptography SLIM algorithm is suitable for use in constraint RFID systems.
systems. SLIM is a block cipher based on a 32-bit block size Feistel structure. SLIM uses a long key length equal to 80-bits to avoid exhaustive key searches. SLIM uses a strong four Feistel structure. SLIM uses a long key length equal to 80-bits to avoid exhaustive key searches. SLIM proved to be highly efficient compared to other existing and implemented algorithms, especially Wireless Sensor Networks (WSNs) and IoT systems. SLIM is a block cipher based on a 32-bit block size and ultra-lightweight block cipher. SLIM is a block cipher based on a 32-bit block size and ultra-lightweight block cipher. The Design Rijndael: AES—The Advanced Encryption Standard (Information Security and Cryptography). Cham, Switzerland: Springer, 2002.

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