

Homomorphic Encryption as End-to-End Solution for Smart Devices

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Abstract

The recent past has seen a tremendous amount of advancement in the field of Internet of Things (IoT), allowing the influx of a variety of devices into the market. IoT devices are present in almost every aspect of our daily lives. While this increase in usage has many advantages, it also comes with many problems, including and not limited to, the problem of security. There is a need for better measures to be put in place to ensure that the users' data is protected. In particular, fitness trackers used by a vast number of people, transmit important data regarding the health and location of the user. This data is transmitted from the fitness device to the phone and from the phone onto a cloud server. The transmission from device to phone is done over Bluetooth and the latest version of Bluetooth Light Energy (BLE) is fairly advanced in terms of security, it is susceptible to attacks such as Man-in-the-Middle attack and Denial of Service attack. Additionally, the data must be stored in an encrypted form on the cloud server; however, this proves to be a problem when the data must be decrypted to use for running computations. In order to ensure protection of data, measures such as end-to-end encryption may be used. Homomorphic encryption is a class of encryption schemes that allow computations on encrypted data. This paper explores the application of homomorphic encryption for fitness trackers.

Keywords:

Internet of Things, Security, Homomorphic encryption, Denial of Service, Decryption, cloud server.

1. Introduction

Internet of things is a system of interrelated and connected objects which are capable of collecting and transferring data through wired and wireless networks without human intervention. It helps people live and work smarter. It is considered as the next evolution of the internet wherein every entity will have the potential to connect to the internet. In the upcoming years with the advancement in technology it will provide an advanced level of services and nearly change the way the people live.

With the rapid developments in IoT technology, the number of connected devices are also increased. Since the main functionality of IoT devices depends on the software and hardware along with its connectivity, securing them is the most important task that should be taken care of. Therefore, providing connectivity with high level of security becomes one of the main objectives of IoT security.

Security in IoT refers to providing confidentiality, integrity, authenticity, privacy and security of users' sensitive data. It is gaining importance not just due to an increase in number of devices but also due to the influx of security issues arising in the different IoT layers. The challenges especially arise in the physical, network and application layer as further explored in this section.

Physical damage, hardware failure, and power limitations are a number of the challenges faced within the physical layer. Some of the attacks that the network layer is susceptible to include DoS attacks, sniffing, gateway attacks, and unauthorized access. Malicious code attacks, vulnerabilities and bugs within the software pose a threat to the application layer [16]. An important aspect of IoT is its application in the field of healthcare, from heart rate monitors to blood sugar monitors and even fitness trackers used by the general population. The data collected and communicated by such devices is highly sensitive and personal to the individual user. In such cases, security holds more importance than before. The case of fitness trackers was considered for this particular project. In order to ensure secure transmission and storage of data, a method for end-to-end encryption using homomorphic encryption is proposed.

2. Related work

Security in IoT devices has been implemented in a variety of methods, from encryption protocols [9], to authentication protocols, blockchain and by making use of Machine Learning and Deep Learning [2].

Hussain, Hussain, Hassan and Hossain, [2] reported in their survey the various ML and DL based methods to enhance IoT security, including the usage of algorithms such as SVM, Naive Bayes, Decision Tree, Random Forest. They also emphasize the problem of consumption of more processing power and energy for implementing ML and DL algorithms. The implementations covered are for various problems that arise in IoT, such as for authentication and access control methods like Q-Learning can be employed as shown in Xiao, et.al.[3], ML based techniques also find use in attack detection and mitigation as shown in [4-6]. DL-based methods have applications in mitigating Denial of Service and Distributed Denial of Service attacks, [7].

Prasitsupparote, Amonrat, Yohei Watanabe, and Junji Shikata [18] proposed a methodology to implement homomorphic encryption in health care systems. They demonstrated the usage of homomorphic encryption in constrained devices by implementing libraries on Raspberry Pi along with a PC acting as a cloud server.

Fitness trackers themselves, employ end-to-end encryption such as AES encryption protocol as shown by Classen, et al. [9]. The authors worked with a FitBit to investigate the security measures employed by the manufacturers. For symmetric key encryption, a 128-bit secret key which is manufacturer-generated is used. Further, it was found that most models that were manufactured before 2015 had optional encryption only. A proprietary technique was seen to be employed for the authentication and pairing process, which cannot be completed without logging into the FitBit smartphone application. Local pairing, however, was not secured. The paper also served the purpose of highlighting the importance of end-to-end encryption in fitness trackers.

Homomorphic encryption is one such encryption protocol that can be used for IoT [10,11]. Song, Hu, Zhao, [11] introduce a modified version of Gentry's homomorphic encryption [17] that can be implemented for IoT security. The author's improved the efficiency of the bootstrapping by optimizing its parameters. They also contribute a method by which the ciphertext modulus can be generalized to be used in a larger variety of situations.

A large number of IoT devices rely on cloud services for storage of data, and ML computations for manipulation of data; Sun, et al. [10] describes the implementation of an improved Fully homomorphic Encryption protocol for multiplicative homomorphic computations, decreasing the noise and modulus by making use of modulus switching and re-linearization techniques. The authors were able to implement classification algorithms like Naive Bayes on FHE encrypted data. Additionally, the processing was further optimized by SIMD used along with their FHE scheme.

Homomorphic encryption can be applied to different types of IoT applications by designing the homomorphic operations in an efficient manner for the encrypted data. Gahi, Guennoun, El-Khatib [12] proposed a prototype database that stored and queried data which was encrypted using fully homomorphic encryption scheme. The authors proposed the circuits required to carry out SQL queries such as SELECT and UPDATE on the encrypted data. While the processing time to carry out the operations was found to be substantial, the work done by the authors shows the scope of homomorphic encryption for application in cloud based services.

Homomorphic encryption does not prove to be a hindrance in providing security from attacks such as code injection as shown in Sgaglione et al.[13], where a Signature-based Intrusion Detection System was implemented such that it processed encrypted data in order to prevent attacks. This ensures security while also maintaining the privacy of data.

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Such applications of Homomorphic Encryption, along with existing methods of IoT Security, provide the required encouragement and guidance for us to implement Homomorphic Encryption as an end-to-end encryption scheme in fitness trackers.

3. Motivation of the work

The literature review conducted pointed towards the need for implementing methods to strengthen the security for IoT devices, especially at cloud level, and at the same time make it possible to carry out data processing. The

proposed system aims to focus on this aspect without compromising on the functionality of the fitness device under consideration. The system aims to allow the usage of third party cloud services while maintaining privacy of the users and allowing the service providers to carry out analysis on the data flow.

4. Terminologies used

Homomorphic encryption schemes refer to those which allow evaluations to be carried out on encrypted data without first decrypting the data. This was first proposed by Rivest, et al. [1], and a fully homomorphic encryption scheme was introduced by Craig Gentry [17] and since, many different schemes have been implemented with varying degrees of efficiency and applicability.

Every scheme consists of different implementations in one or more of the following algorithms: Key Generation, Encryption, Decryption, or Evaluation algorithms. All four of these algorithms form the core implementation of any homomorphic scheme. Homomorphic Encryption schemes can be additive or multiplicative or both, depending on which they can be classified as Fully Homomorphic, Somewhat Homomorphic, and Partially Homomorphic Encryption. These vary not only in terms of operations performed but also the number of operations that can be accurately performed.

Consider a homomorphic function $E()$ that is used to encrypt messages, m_1 and m_2 . Once the data has been encrypted, addition and multiplication computations can be carried out on the now encrypted data, $E(m_1)$ and $E(m_2)$. The decrypted result will be equal to the result as when the computation is carried out on the unencrypted data.

For two plaintext data, m_1 and m_2 ,

$$E(m_1) + E(m_2) =$$

$$E(m_1 + m_2)E(m_1) *$$

$$E(m_2) = E(m_1 * m_2)$$

In the above equations, $E()$ represents homomorphic encryption function [1]. As shown, this has numerous applications due to its capability of preserving privacy while allowing computations of data. Depending on the implementation and type of homomorphic encryption

used, some noise may be introduced in the result, which may increase with the number of computations depending on the scheme used.

5. Proposed method

Taking into consideration the work done for end-to-end encryption in the field of internet of things, including the use of homomorphic encryption, we propose a model for providing increased security for fitness trackers. There are three entities considered for the data transaction: the tracker device, the user's smartphone and the cloud server. The communication channels exist between the tracker and the Smartphone, and between the Smartphone and the cloud server. The tracker and the smartphone are connected by a Bluetooth low energy standard 5.2 connection. The data transmission between the phone and the cloud takes place over a standard internet connection.

The cloud server is considered to be a semi trusted third party cloud server. This entails that the data must be securely transmitted and additionally, must be encrypted even when stored on the cloud server. As explained earlier, the usage of homomorphic encryption ensures decryption is not necessary in order to carry out computation on encrypted data. Thus, homomorphic encryption is employed in the system.

Specifically, the CKKS (Cheon Kim Kim Song [14]) scheme is used. This scheme is a partially homomorphic encryption scheme that can encrypt real as well as complex numbers. It allows computations on complex numbers in the form of vectors. CKKS scheme gives approximate results after decryption and computation. For example, the number zero after encryption followed by decryption may result in a fractional number of the order of 10^{-8} . Although the results will be approximate, the applicability of this scheme for real numbers comes in use for the fitness tracker data, which usually consists of real numbers such as distance, GPS coordinates, time, calorie count, heart rate, etc. The homomorphic encryption process itself consists of four major steps: key generation, encryption, decryption and computation.

In our proposed system, the key generation takes place on the smartphone. Once the public and secret keys have been generated, the public key is transmitted to the paired device, while the secret key remains with the smartphone. In the device, the various sensors collect and accumulate the data during any activity. This data is encrypted according to the CKKS scheme using the public key that has been transmitted to it. The encrypted data is then transmitted via Bluetooth to the phone, where some of the data, such as

dataset. This comparison was done to further highlight the performance of HELib against other available libraries for homomorphic encryption. Both SEAL and HELib show promising results in terms of speed of encryption, and decryption. HELib was then used for further experimentation as detailed below.

An additional operation considered is that of carrying out the calculation of Euclidean distance on two points in the x-y plane. This operation was carried out to check the feasibility of using homomorphic encryption for fitness trackers, where the Euclidean distance is used to calculate distance between GPS coordinates. The Euclidean distance calculation is divided into the following steps: first the subtraction is done before encryption, then the squaring and addition operations are carried out on the encrypted data, and next, the data is decrypted and the square root value is found. This is the proposed method for calculation of distance in fitness trackers where the calculation occurs at the cloud level and the operations on the decrypted data occurs at the smartphone level. The distance values must be initially converted from GPS coordinates to UTM coordinates. The results are shown in Table II, and the time taken to complete this operation was 0.063522 seconds on the considered system.

TABLE I
TIME TAKEN (IN SECONDS) FOR DIFFERENT ACTIONS CARRIED OUT ON A DATASET HAVING 1095 DATA ITEMS.

Action	HELlib	Microsoft SEAL
Secret Key Generation	0.0199 sec	0.0650 sec
Encryption	0.0676 sec	0.0608 sec
Decryption	0.050229 sec	0.0094 sec

Although the experiments carried out in this paper are with respect to a fitness tracker, the results remain same for any other smart devices that uses cloud based operations. The paper proposes an efficient way of encryption technique that can be used in smart devices aiming at a higher level of security for a user's data. Hence, the privacy of the data is taken care and is not compromised.

TABLE II
RESULTS OBTAINED FOR EUCLIDEAN DISTANCE BETWEEN TWO POINTS, IMPLEMENTED IN HELIB

Coordinates considered: (E:600.0,N:6100.0), (E:400.0,N:6250.0)		
Operation	Expected value	Generated value
Squaring x coordinates	40000.00	40000.00
Squaring y coordinates	22499.99	22500.00
Addition	62499.99	62500.00
Final value (after decryption)	249.99	250.00

7. Conclusion

The increasing interest in fitness has caused a massive increase in the usage of fitness trackers amongst people of all ages. This has led to a host of problems in terms of security and privacy. We have worked on this issue and proposed a method to alleviate the problem of privacy when data is stored on cloud servers. Homomorphic encryption is an encryption technique that caters to such situations as it can not just provide cryptographic protection but also, allow computation on encrypted data without having to decrypt the data first.

We believe that implementing such an end-to-end solution would enhance the security of the fitness tracker devices greatly. The HELib library shows immense potential to be applied for this purpose with its ability to generate near accurate values after computations. Further work can be done in providing authentication, integrity and confidentiality features over the encryption layer to further strengthen the data transmission channels.

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