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A Novel Technique for Device Encryption on Android Platform for Data Restoration

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ABSTRACT: In modern communication system, communication through mobile phones plays a vital role where mobile phones have become part and parcel of common man's daily life. At the same time there is every possibility of losing the phones either by misplacing the hand set or the same being theft. In such cases whatever the data stored by the owner of the mobile should be protected, This paper proposes a technique for data restoration by improvising the use of On Device Encryption, ODE which is a solution provided from Google and used for encrypting user data (/data), so that if phone is lost, user data is recoverable. By default, ODE encrypts whole partition for /data, but from Lollypop OS, Fast Encryption technique encrypts only valid data present on device, so encryption is much faster than earlier versions.

KEYWORDS: ODE, Fast Encryption, Android OS, Disk Encryption.

I. INTRODUCTION

Disk encryption uses an encryption algorithm to convert every bit of data that goes to disk to Cipher text, ensuring that data cannot be read from the disk without the decryption key. The disk decryption key is usually stored, encrypted and requires an additional key encryption key (KEK) in order to be decrypted. The KEK can either be stored in a hardware module, such as a smart card or a TPM, or derived from a passphrase obtained from the user on each boot. When stored in a hardware module, the KEK can also be protected by a user-supplied PIN or password. Android's disk encryption uses dm-crypt, currently the standard disk encryption subsystem in the Linux kernel. Like dm-verity, dm-crypt is a device-mapper target that maps an encrypted physical block device to a virtual device-mapper device. All data access to the virtual device is decrypted (for reads) or encrypted (for writes) transparently.

The encryption mechanism employed in Android uses a randomly generated 128-bit key together with AES in CBC mode. CBC mode requires an initialization vector (IV) that needs to be both random and unpredictable in order for encryption to be secure. This presents a problem when encrypting block devices, because blocks are accessed non-sequentially and therefore each sector (or device block) requires a separate IV.

Android uses the encrypted salt-sector initialization vector (ESSIV) method with the SHA-256 hash algorithm (ESSIV: SHA256) in order to generate per-sector IVs. ESSIV employs a hash algorithm to derive a secondary key s from the disk encryption key K, called a salt. It then uses the salt as an encryption key and encrypts the sector number SN of each sector to produce as per sector IV. In other words, IV (SN) = AESs (SN), where s = SHA256 (K).

Because the IV of each sector depends on a secret piece of information (the disk encryption key), per-sector IVs cannot be deduced by an attacker. However, ESSIV does not change CBC's malleability property and does not ensure the integrity of encrypted blocks. In fact, it's been demonstrated that an attacker who knows the original plaintext stored on disk can manipulate stored data and even inject a backdoor on volumes that use CBC for disk encryption.

II. KEY DERIVATION

A. EXPERIMENTAL KEY-DERIVATION

The disk encryption key (called the "master key" in Android source code) is encrypted with another 128-bit AES key (KEK), derived from a user-supplied password. In Android versions 3.0 to 4.3, the key derivation function used was PBKDF2 with 2,000

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iterations and a 128-bit random salt value. The resulting encrypted master key and the salt are stored, along with other metadata like the number of failed decryption attempts, in a footer structure occupying the last 16 KB of the encrypted partition, called a crypto footer. Storing an encrypted key on disk instead of using a key derived from the user-supplied password directly allows for changing the decryption password quickly, because the only thing that needs to be re-encrypted with the key derived from the new password is the master key (16 bytes). While using a random salt makes it impossible to use precomputed tables to speed up key cracking, the number of iterations (2,000) used for PBKDF2 is not sufficiently large by today's standards. (The Keystore key derivation process uses 8,192 iterations as discussed in Chapter 7. Backup encryption uses 10,000 iterations, as discussed later in "Android Backup".) Additionally, PBKDF2 is an iterative algorithm, based on standard and relatively easy to implement hash functions, which makes it possible for PBKDF2 key derivation to be parallelized, taking full advantage of the processing power of multi-core devices such as GPUs. This allows even fairly complex alphanumeric passphrases to be brute-force in a matter of days, or even hours.
In order to make it harder to brute-force disk encryption passwords, Android 4.4 introduced support for a new key derivation function called Scrypt. Scrypt employs a key derivation algorithm specifically designed to require large amounts of memory, as well as multiple iterations (such an algorithm is called memory hard). This makes it harder to mount brute-force attacks on specialized hardware such as ASICs or GPUs, which typically operate with a limited amount of memory.

There are four constrains in ODE,

- Battery Power should be 80% before starting Encryption. Even if user having very limited data e.g. 1 GB, which required lets a 20% of power; user has to charge 80% before starting encryption as shown in Figure 3.
- Phone should be in charging mode, i.e. power cable should be connected. Again if user having sufficient power, power cable connection is burden for user.
- After encryption started, if we removed power charger, no warning message shown. If battery power dissipation rate is too high and device having maximum data that need to encrypt, there is no guarantee 80% power will be enough to complete encryption.
- Once encryption started, can't be halted/paused. If we have large data and battery charge is available at starting, now after some time, user removed power charging cable and battery power dissipation rate is too high, ODE module should calculate dynamically remaining power required and if required, show user warning message to connect power charging and pause encryption process.
- Now we are working further where if user can't connect / ignore to power source after it shows warning message to connect power cable as shown in Figure 4, then encryption can be paused, save its current state like no of blocks encrypted, and unfinished blocks and rebooted and when power cable is connected, again we can resume encryption, from where we left.

B. BATTERY TYPES DISCHARGE CURVES

Below diagram shows the discharge curves of different types of battery. As plotted in Figure 1, Power dissipation rate if not linear in battery and varying on different types of cell.

With our proposed solution, we can not apply a linear algorithm to calculate power required for encryption of particulate amount of data. We need to preprocessed some data and make some graph to predict a power consumption for a random amount of power requirement. Also need to take care of small amount of offset power to add, required for safety, since power dissipation rate is increase with older battery.

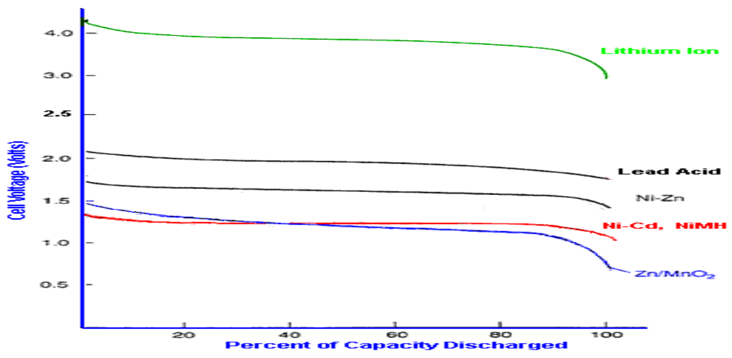

Figure 1: Normal Discharge Rate Plot

The graph below shows typical discharge curves for cells using a range of cell chemistries. Note that each cell chemistry has its own characteristic nominal voltage and discharge curve. Some chemistries such as Lithium Ion have a fairly flat discharge curve while others such as Lead acid have a pronounced slope.

The power delivered by cells with a sloping discharge curve falls progressively throughout the discharge cycle. This could give rise to problems for high power applications towards the end of the cycle. For low power applications, which need a stable supply voltage, it may be necessary to incorporate a voltage regulator if the slope is too steep.

III. PROPOSED MODEL

Few improvements have been done till now so that where user does not need to charge 80% of power before starting encryption as shown in Figure 3 and the power cable need to be connected depending on required data present in /data partition. During encryption if there is shortage of power for unavoidable cause, encryption will be paused and warning message will be shown to connect power cable as shown in Figure 2.
The Figure 2 shows the difference in flow of Operation in current scenario and proposed solution. In Proposed solution, it is dynamically checking for the power requirement with respect to the data need to be encrypted.

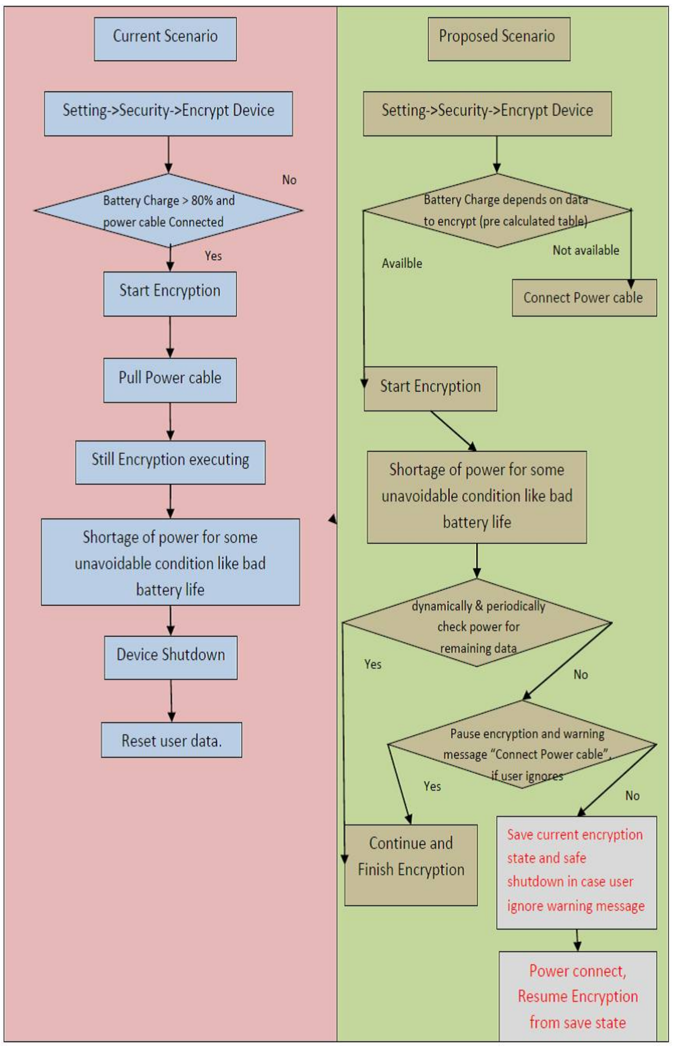
Current Scenario
Setting->Security->Encrypt Device
Battery Charge > 80% and power cable Connected
No
Yes
Start Encryption
Pull Power cable
Still Encryption executing
Shortage of power for some unavoidable condition like bad battery life
Device Shutdown
Reset user data.
Proposed Scenario
Setting->Security->Encrypt Device
Battery Charge depends on data to encrypt (pre calculated table)
Availble
Not available
Connect Power cable
Start Encryption
Shortage of power for some unavoidable condition like bad battery life
dynamically & periodically check power for remaining data
Yes
No
Pause encryption and warning message "Connect Power cable", if user ignores
Yes
No
Continue and Finish Encryption
Save current encryption state and safe shutdown in case user ignore warning message
Power connect, Resume Encryption from save state

Figure 2: Existing Encryption Flow vs Proposed Encryption flow

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IV. RESULTS & DISCUSSION

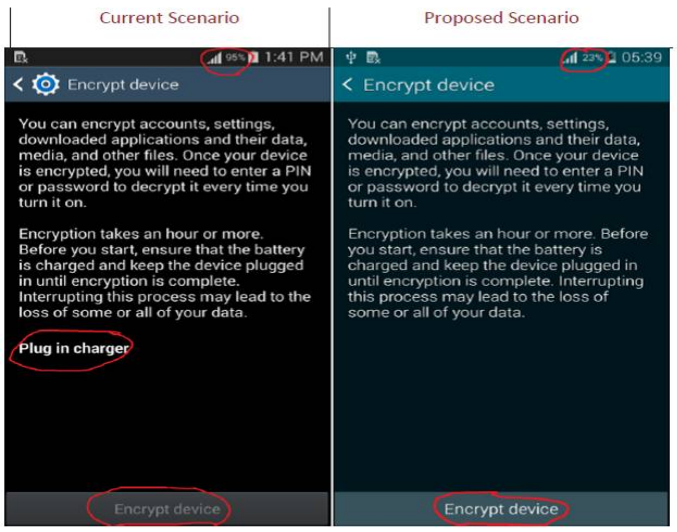
C.A. PROPOSED MODEL RESULTS

Below are few output screenshots Figure 3 & 4 to explain our proposed model,

- For normal case, even if power is 95%, power source need to connect, else "Encrypt Device" option will be disabled. One improvement version will start encryption with 23% of power, i.e. depending of amount of data required to encrypt.

- Google support only full encryption until KitKat where all blocks in /data partition will be encrypted even if no valid data is not present. From Android 5.0 (Lollipop) support Fast Encryption, where only valid memory block will be encrypted. So our implementation will be for Fast encryption always, so removed "Fast Encryption" option, as it's not option for our experiments. For full encryption power requirement is constant and our implementation is not required
- Now during Encryption for some rare and unavoidable case, device is short of power and power source is disconnected, for current implementation it will continue to encrypt and possibility of data corruption, where new implementation will

  pause encryption to save some power (CPU cycles) and warning message to user to connect power source to continue, after user connect power cable, encryption will resume its operation.



Encrypt device

You can encrypt accounts, settings, downloaded applications and their data, media, and other files. Once your device is encrypted, you will need to enter a PIN or password to decrypt it every time you turn it on.

Encryption takes an hour or more. Before you start, ensure that the battery is charged and keep the device plugged in until encryption is complete. Interrupting this process may lead to the loss of some or all of your data.

Plug in charger

Encrypt device

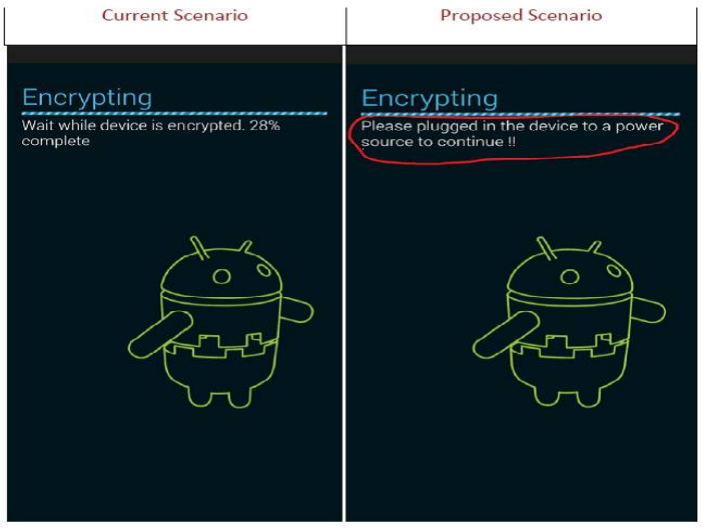
Encrypt device

You can encrypt accounts, settings, downloaded applications and their data, media, and other files. Once your device is encrypted, you will need to enter a PIN or password to decrypt it every time you turn it on.

Encryption takes an hour or more. Before you start, ensure that the battery is charged and keep the device plugged in until encryption is complete. Interrupting this process may lead to the loss of some or all of your data.

Encrypt device

Figure 3: Existing Encryption Menu Screen vs Proposed Encryption Menu Screen



Encrypting

Wait while device is encrypted. 28% complete

Encrypting

Please plugged in the device to a power source to continue !!

Figure 4: Existing Encryption Progress Screen vs Proposed Encryption Progress Screen

In Fig 3: Shows behavior before encryption for power cable for existing and proposed method.
In Fig 4: Shows behavior during encryption for existing and proposed method. In case of proposed method, if there is lack of power, encryption process stop and ask to connect power source to resume encryption.

D. BATTERY TYPES DISCHARGE CURVES

The Power required is calculated as follows

Pr (mAh) = Amount of Data to encrypt (GB) * Power consumption (mAh) to encrypt single block (l GB)

Problem with above approach is that battery discharge rate very with different battery charge position. Let say while in 90% change, it required 100 mAh to encrypt 1 GB of data, where as in 20% change, it required 125 mAh of power

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for same amount of data to encrypt.To avoid such linear approach, here we used some pre-calculated data based on our experiments.

Power Required Pr (mAh) = Power (P) for x GB data + Offset ------------------- (1)

Where P(x+1) < P(x) < P(x-1)

I.e. Power consumption P(x) for x GB of data encryption need to be pre-calculated value. Like 24.3 GB data, need power consumption between 24.1 GB ~ 24.9 GB. E.g. 100 mAh.

Here "Offset" value has taken, based upon precaution. Because of old battery has larger battery discharge rate.

V. EXPERIMENTS & OBSERVATIONS

E. TEST SETUP

A test has been prepared with below parameters

- Battery Capacity: 4600 mAh
- Available Memory: 22GB
- Total Space : 32 GB

F. PLOT OF DATA ENCRYPTED VERSES POWER

'Voltage' column depicts power consumption before and after encryption in mAh unit.
'Difference' column depicts power consumption of data encryption of 'Data Size' column in Giga Byte units.

Sl	Voltage (Before / After)	Difference	Data Size (in GB)
1	4346 / 4146	200	22 GB
2	4238 / 4126	112	20 GB
3	4142 / 3971	171	18 GB
4	4298 / 4194	104	16 GB
5	4173 / 4053	120	14 GB
6	4172 / 4073	99	12 GB
7	4161 / 4019	142	10 GB
8	4205 / 4096	109	08 GB
9	4301 / 4205	96	06 GB
10	4183 / 4168	15	04 GB
11	4342 / 4209	133	02 GB

Table 1: Power Saved per Encryption Data Size

G. C*OMPARATIVE* S*TUDY OF VOLTAGE USAGE PER* E*NCRYPTING*

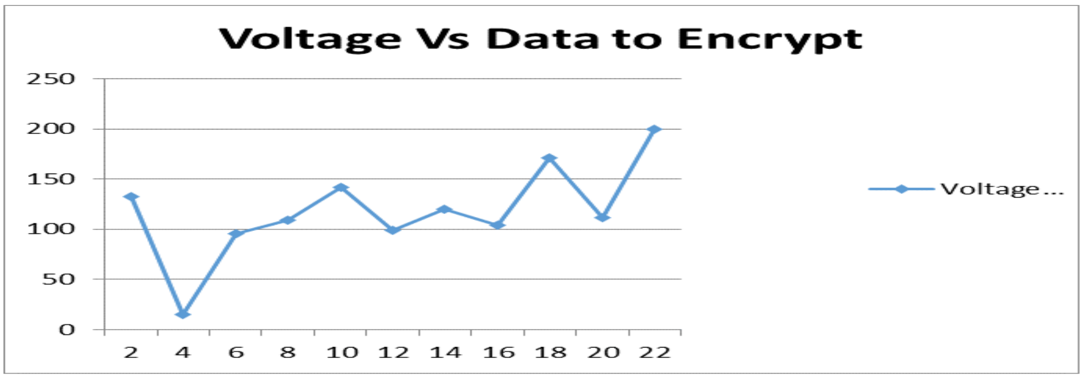

Figure 5: Graphical representation of Power Saved per Encryption Data Size

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Above graph in figure 5 represents the power consumption can be saved per encrypting data size in GB. This graph represents

the power consumption difference mentioned in Table 1. As stated in table 1, Approximately 133 voltage can be saved while encrypting 2 GB of Data. On an average, we are saving 100 ~ 150 voltage with the proposed solution.

VI. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.
These experiments have been done based on Android lollipop 5.1 version. In case of Android Disk Encryption, Google supports Fast Encryption which encrypts only the valid data present on device, so current encryption proposed method is much faster than earlier version and overcome following four constraints:

- Battery Power should be 80% before starting Encryption
- Phone should be in charging mode
- After encryption started, if we removed power charger, no warning message shown
- Once encryption started, it can’t be halted/paused.

Here one can calculate power requirement based on user data to encrypt. Most of the time, if user data has limited data, 80% charge is not required. So, with proposed method, one can calculate power requirement dynamically, based on amount of data which can save the power and overcome current restriction to user.

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BIOGRAPHY

Bappa Mondal, has received Bachelor of Technology from Dr. B. C Roy Engineering College. Currently pursuing his Master Degree from Delhi technological University. He has 10+ years of work experience and widely working on information security on embedded devices.

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