A Brief Survey on RC4 Cryptography

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***Abstract*—RC4 is a stream cipher which was most widely accepted for its structural simplicity. It has high rate of encryption and decryption rate i.e speed and efficiency. There were several reports on RC4 algorithm vulnerabilities and further proposals on modified RC4 algorithm. In spite of all these vulnerabilities still RC4 is been used in TSL web connections. There were many efforts on removing weakness of RC4 such as biased key , key collisions, key recovery etc , specifically from WEP ,so WPA standard was introduced to over come these vulnerabilities . WPA was again proved insecure due to TB data injection attack.researchers are working on RC4 from past two decades but still the attraction towards RC4 has been alive.**

***Index Terms*—RC4 , cryptography , stream cipher , algorithm , survey**

I. Introduction

RC4(Rivest Cipher 4) is also known as ARC4 or ARCFOUR meaning Alleged RC4. RC4 is a stream cipher , which is known for its simplicity and speed in software . RC4 became a part of encryption protocols and standards, such as WEP in 1997 , WPA in 2003 for wireless cards , and SSL in 1995 and its successor TLS in 1999 , until it was prohibited in 2015 due to RC4 attack or breaking RC4 used in SSL/TLS. RC4 was very easy to implementation on software and hardware devices. RC4 is a symmetric encryption where single key is shared between both the parties to encrypt and decrypt the cipher [1] Secret key ciphers are further classified as stream ciphers and block ciphers.RC4 is a Stream cipher which means it encryption takes palace bit by bit where as in block ciphers it the encryption will take place in a fixed size block. The strength of the stream cipher depends on the random key stream generated which is then xor-ed with the plaintext.

II. Algorithm

RC4 algorithm has 2 main components KSA(Key-scheduling algorithm) and PRGA(Pseudo-random generation algorithm) . The secret key is passed though KSA and PRGA the output is bitwise xored with plaintext. It is similar to one time pad expect that the pseudorandom number generated by PRGA is used rather than prepared streams.

KSA is used for initializing the S array , the output is given to PRGA.

KSA algorithm

```
for i from 0 to 255
    S[i] := i
endfor
j := 0
for i from 0 to 255
    j := (j + S[i] + key[i mod keylength]) mod 256
    swap values of S[i] and S[j]
endfor
```

For as many iterations as are needed, the PRGA modifies the state and outputs a byte of the keystream. In each iteration, the PRGA.

PRGA algorithm

```
i := 0
j := 0
while GeneratingOutput:
    i := (i + 1) mod 256
    j := (j + S[i]) mod 256
    swap values of S[i] and S[j]
    K := S[(S[i] + S[j]) mod 256]
    output K
endwhile
```

the output K stream is xored with the plaintext to encrypt the data , or it is xored with ciphertext to decrypt the data.

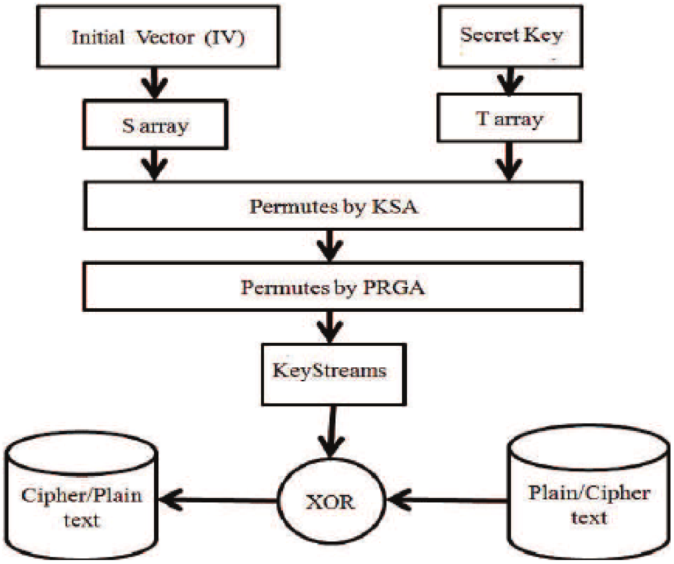


Fig. 1. RC4 flow diagram

III. Modification Approaches

PSEUDO CODE I

KSA OF IMPROVED RC4 PROPOSED BY JIAN XIE ET AL:[2].

```
for i = (0 to N-1)
{
    S1[i]=i;
    S2[i]=i;
}
j1=j2=0;
for i = 0 to N-l
{
    j1 = ( j1+S1[i]+kl[i]) mod N;
    swap(S1[i], S1[j]);
    j2=( j2+S2[i]+k2[i]) mod N;
    swap(S2 [i], S2[j]);
}
```

PSEUDO CODE II

PRGA OF IMPROVED RC4 PROPOSED BY JIAN XIE ET AL:[2].

```
i=j1=j2=0;
Loop
{
    i=i+1;
    j1= j1+S1[i];
    swap(S1[i], S1[j]);
    j2= j2+S2[i];
    swap(S2[i], S2[j]);
    Output = S1  [(S1  [i]+ S1[j]) mod N];
    Output= S2[(S2  [i]+ S2[j]) mod N];
    swap(S1[S2[j1]], S1[S2[j2]]);
    swap(S2[S1[j1]], S2[S1[j2]]);
}
```

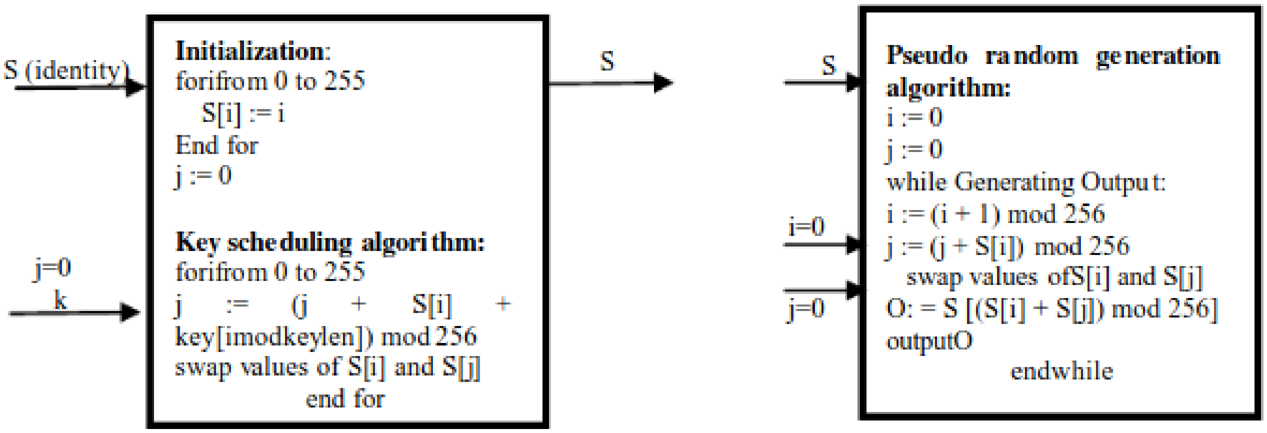
Many more modification on RC4 are made in decades to improve security as well as speed .

IV. Security Analysis

- RC4 is extensively used in WLAN security protocols. WEP (Wired equivalent privacy) was the first security protocol used for Wi -Fi security in IEEE 802.11 LANs and is based on RC4 encryption algorithm. Due to the number of attacks on WEP such as; related key attacks[3], Fluhrer, Mantin and Shamir attack (FMS)[4], Korek practical attacks[5], Mantin attack on RC4 [6] and WEP,and many many more threfore WEP was declared as an insecure protocol.
- WPA defended against many attacks in WEP. WPA has again proved to be a weak protocol due to TB data injection attacks[7], and SVV attacks[8]. new protocol WPA2 was proposed which uses AES block cipher as an encryption algorithm instead of RC4. Though WPA2 is a secure protocol, removing many vulnerabilities of WEP. hardware based applications which uses WEP and WPA with RC4 were cost effective.
- RC4 is also broadly accepted in web security. It is used in TLS (Transport layer security) /SSL to offer security over the internet. The RC4 is known to the best choice for TLS/SSL as it can mitigate many attacks on the protocol. However recently in 2013 and 2014, a new security attack[9] on RC4 of Although there had been many successful security breaches in the protocols using RC4, but the striking combination of robustness and design elegance of RC4 has made it most preferred protocol for last two decades.

V. Application

RC4 was widely used in WLAN connection in WEP and WPA . WPA2 uses AES for better security . RC4 was been used in TLS/SSL before 2015 which is no more used in web security. versions of RC4 is used in bluetooth , radios and many more small devices which has low computation power but yet security is important There are many variant of RC4 like RC4A proposed by Souradyuti Paul and Bart Preneel [10]
VMPC(Variably Modified Permutation Composition) [11]
Spritz by Rivest, Ron; Schuldt, Jacob (27 October 2014)[12].
RC4+ by Subhamoy Maitra; Goutam Paul (19 September 2008)[13]



```
Initialization:
forifrom 0 to 255
   S[i] := i
End for
j := 0

Key scheduling algorithm:
forifrom 0 to 255
j := (j + S[i] + key[imodkeylen]) mod 256
swap values of S[i] and S[j]
          end for
```

```
Pseudo random generation algorithm:
i := 0
j := 0
while Generating Output:
i := (i + 1) mod 256
j := (j + S[i]) mod 256
  swap values ofS[i] and S[j]
O: = S [(S[i] + S[j]) mod 256]
outputO
            endwhile
```

a) RC4 Key scheduling algorithm   b) RC4 Pseudo random generation algorithm

Fig. 2. RC4

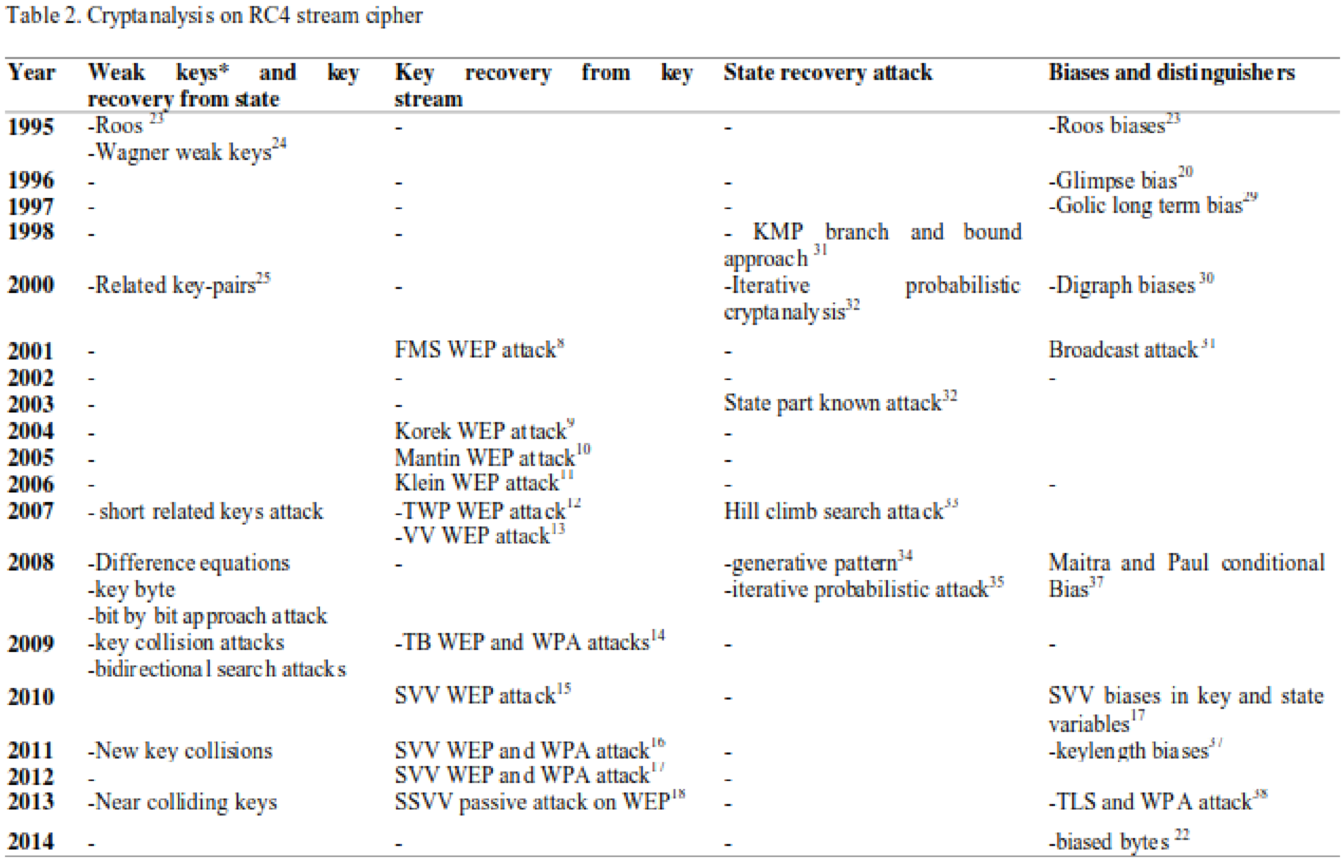


Table 2. Cryptanalysis on RC4 stream cipher

Year	Weak keys* and key recovery from state	Key recovery from key stream	State recovery attack	Biases and distinguishers
1995	-Roos [23] -Wagner weak keys[24]	-	-	-Roos biases[23]
1996	-	-	-	-Glimpse bias[20]
1997	-	-	-	-Golic long term bias[29]
1998	-	-	- KMP branch and bound approach [31]	
2000	-Related key-pairs[25]	-	-Iterative probabilistic cryptanalysis[32]	-Digraph biases [30]
2001	-	FMS WEP attack[8]	-	Broadcast attack [31]
2002	-	-	-	-
2003	-	-	State part known attack[32]	
2004	-	Korek WEP attack[9]	-	
2005	-	Mantin WEP attack[10]	-	
2006	-	Klein WEP attack[11]	-	-
2007	- short related keys attack	-TWP WEP attack[12] -VV WEP attack[13]	Hill climb search attack[33]	
2008	-Difference equations -key byte -bit by bit approach attack	-	-generative pattern[34] -iterative probabilistic attack[35]	Maitra and Paul conditional Bias[37]
2009	-key collision attacks -bidirectional search attacks	-TB WEP and WPA attacks[14]	-	-
2010		SVV WEP attack[15]	-	SVV biases in key and state variables[17]
2011	-New key collisions	SVV WEP and WPA attack[16]	-	-keylength biases[37]
2012	-	SVV WEP and WPA attack[17]	-	
2013	-Near colliding keys	SSVV passive attack on WEP[18]	-	-TLS and WPA attack[38]
2014	-	-	-	-biased bytes [22]

Fig. 3. list of known weakness of RC4

Conclusion

In this paper i have presented a brief study of RC4 ,about is robust feature and its weaknesses . How easy it is to implement on hardware and software .We have presented a broad varieties of RC4 algorithms improving the security aspects of RC4 . It was widely used in wireless communication(like WEP and WPA) and web security like TLS/SSL until it was declared to be insecure . . Further inspite of all the developments reported in the literature, there are still many open research challenges and issues related to searches of more biases, key collisions in keystream, and key recovery attack on WPA .The conclusion is there is still research going on , on RC4 to make it more efficient and effective encryption algorithm.

Acknowledgment

Thanking the PES Institution and the Teachers for their support, Guidance and encouragement.

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