Cryptanalysis of the Windows Random Number Generator

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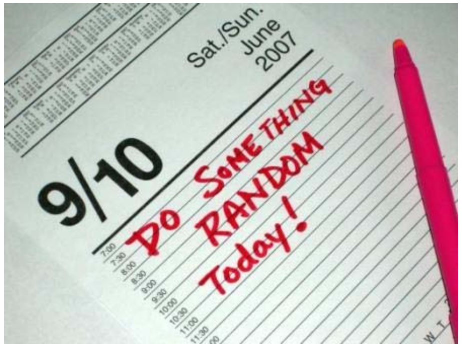

Presentation based on paper: Cryptanalysis of the Random Number Generator of the Windows Operating System; published by L. Dorrendorf, Z. Gutterman, and Benny Pinkas.

Outline

- Basic information
- Analysis of the Windows PRNG
- Attacks on forward security
- Attacks on backward security
- Usage of Windows PRNG

Introduction

- Pseudo-randomness
  - Output of PRNG looks random to outside observer
- Forward security
  - The attacker that know internal state of PRNG cannot learn anything about previous outputs
- Backward security (break-in recovery)
  - The attacker that know internal state of PRNG cannot learn anything about future outputs
- Attacker model
  - Attacker need a state of generator (application, buffer overflow)
    - No additional information from attacked system
  - Compromised state => all previous and future PRNG outputs

The structure of Windows PRNG (WRNG)

- Generator from Windows 2000 binary code
- Based on RC4 and variant of SHA-1 (different IVs)
  - Generates 20 bytes per iteration

```
CryptGenRandom(Buffer, Len)
// output Len bytes to buffer
   while (Len>0) {
      R := R ⊕ get_next_20_rc4_bytes()
      State := State ⊕ R
      T := SHA-1'(State)
      Buffer := Buffer | T
        // | denotes concatenation
      R[0..4] := T[0..4]
        // copy 5 least significant bytes
      State := State + R + 1
      Len := Len − 20
   }
```

- Main state is composed from registers *R* and *State*
  - Not explicitly initialized => latest values in allocated memory

The function get_next_20_RC4_bytes

- Function keeps its own state
  - Eight instances of RC4
  - In each call function performs
    - Select 1 RC4 state (round-robin)
    - Use it to generate 20 byte output
  - Refresh after RC4 instance generates 16 Kbytes of data
- Initializing and refreshing each instance of RC4
  - Entropy gathered from system
  - Collection of 3584 bytes of data
    - Hashed to produce 80-byte digest
  - Used for encryption of seed
    - Accessible in clear-text from registry
  - RC4 encryption of data from driver KSecDD => final RC4 key

- Entropy sources

Source	Size in bytes requested
CircularHash	256
KSecDD	256
GetCurrentProcessID()	8
GetCurrentThreadID()	8
GetTickCount()	8
GetLocalTime()	16
QueryPerformanceCounter()	24
GlobalMemoryStatus()	16
GetDiskFreeSpace()	40
GetComputerName()	16
GetUserName()	257
GetCursorPos()	8
GetMessageTime()	16
NTQuerySystemInformation calls	
ProcessorTimes	48
Performance	312
Exception	16
Lookaside	32
ProcessorStatistics	up to the remaining length
ProcessesAndThreads	up to the remaining length

Scope of WPRNG

- One WPRNG per process (& in user mode)
  - Different process have separate internal states
    - RC4 states (and other variables) are in DLL space
    - *R* and *State* are in stack
  - Different threads in one process
    - Share RC4 states
    - Have own stack (and copy of *R/State*)
- Impacts of scoping
  - Breaking one WRNG does not affect another WPRNG
  - Only one consumer per WRNG => long period between rekeys

Attack on backward security

- Suppose that an adversary knows internal state
- The next state and output are deterministic function of the actual state
- An adversary can compute next state and output until the next refresh of generator

Attacks on forward security

- Instant attack
  - Initial values, state *R* and *State*, 8 RC4 registers are known
  - RC4 does not provide forward security
  - Given a current state we can compute previous states/outputs
- Attacks with overhead 2^{40} and 2^{23}
  - State *R* and *State* are unknown => more complex attacks
    - Based on relations between several values or operations
    - Typically R/S; addition / exclusive or operations
  - The latter attack on Pentium IV 2.80 GHz takes 19 seconds
- Bad design of state updates (xor and +)
  - $S^{t+1}=(S^t \mathrm{xor} R)+R'+1$: R is almost identical to R' (5 bytes replaced with output bytes) => S^{t+1} is strongly related to S^{t+1}

Interaction between OS and Generator I

- Frequency of entropy based rekeys of state
  - 1 process: 1 instance WRNG, 8 RC4 streams => refresh after each 128Kbytes of generated data
  - Between refreshes is generation deterministic
- Entropy based rekeys in Internet Explorer (sec. sensitive app.)
  - During SSL: 4 or more requests for 8, 16, 28 bytes of random data
  - Each SSL connection consumes approx. 100–200 bytes
  - IE asks for refresh only after handling 600–1200 SSL connections
- Initializing state *R* and *State* (not explicitly initialized)
  - First experiment: IE started after rebooting OS
    - Different mappings but correlated values
  - Second experiment: IE was restarted 20times
    - Always same values
  - Third experiment: IE ran in 20 parallel sessions
    - In 19 cases correlated initial values (Hamming distance 10 or less)

Comparison to the Linux PRNG (LRNG)

WRNG

- User mode
  - App. can read state
- Reseeding timeout after 128KBytes of output
- Synchr. collecting of entropy
  - Entropy collected in periods
- Multiple runs of WRNG
- Attack on forward secrecy requires work 2^{64}
- No blocking
  - No entropy measurements

LRNG

- Kernel mode
  - State is hidden to app.
- Reseeding timeout in every iteration
- Asynchr. collecting of entropy
  - Entropy event => pool update
- Single run of LRNG
- Attack on forward secrecy requires work 2^{23}
- Possible blocking (DoS)
  - Entropy counter

Conclusions

- Security through obscurity (or even implementation complexity) do not work
  - Successful attacks are only a question of time
  - Attack on WRNG but also to (complex) open-source LRNG
- WRNG depends on RC4 that do not provide forward security
  - The recommendation is at least to replace this function
  - Better approach: replace whole WRNG and use, for example, by rigorously analyzed Barak-Halevi construction
    - If building blocks are secure then B-H construction provably preservers both forward and backward security
- WRNG also should rekey its state more often
  - Forced rekeys in some time intervals