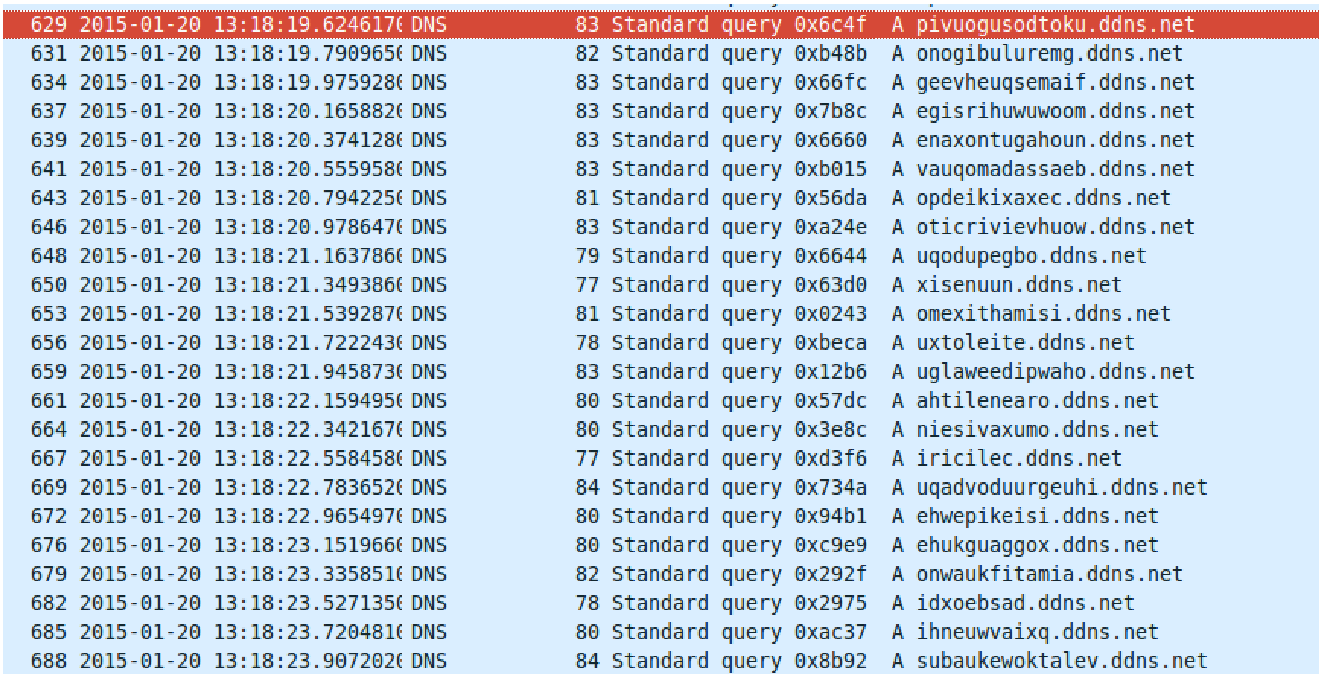
The DGA of Symmi

bin.re/blog/the-dga-of-symmi/

Looking through the most recent reports on malwr.com, a sample sparked my interest because it suits my current interest in domain generation algorithms (DGA). Virus scanners label the sample as *Symmi*, other names for the same or similar malware family are *MewsSpy* and *Graftor*. The sample is very noisy. It tries to resolve many domains in a short period of time — only limited by the response time of the DNS server:



```
629 2015-01-20 13:18:19.624617 DNS          83 Standard query 0x6c4f  A pivuogusodtoku.ddns.net
631 2015-01-20 13:18:19.790965 DNS          82 Standard query 0xb48b  A onogibuluremg.ddns.net
634 2015-01-20 13:18:19.975928 DNS          83 Standard query 0x66fc  A geevheuqsemaif.ddns.net
637 2015-01-20 13:18:20.165882 DNS          83 Standard query 0x7b8c  A egisrihuwuwoom.ddns.net
639 2015-01-20 13:18:20.374128 DNS          83 Standard query 0x6660  A enaxontugahoun.ddns.net
641 2015-01-20 13:18:20.555958 DNS          83 Standard query 0xb015  A vauqomadassaeb.ddns.net
643 2015-01-20 13:18:20.794225 DNS          81 Standard query 0x56da  A opdeikixaxec.ddns.net
646 2015-01-20 13:18:20.978647 DNS          83 Standard query 0xa24e  A oticrivievhuow.ddns.net
648 2015-01-20 13:18:21.163786 DNS          79 Standard query 0x6644  A uqodupegbo.ddns.net
650 2015-01-20 13:18:21.349386 DNS          77 Standard query 0x63d0  A xisenuun.ddns.net
653 2015-01-20 13:18:21.539287 DNS          81 Standard query 0x0243  A omexithamisi.ddns.net
656 2015-01-20 13:18:21.722243 DNS          78 Standard query 0xbeca  A uxtoleite.ddns.net
659 2015-01-20 13:18:21.945873 DNS          83 Standard query 0x12b6  A uglaweedipwaho.ddns.net
661 2015-01-20 13:18:22.159495 DNS          80 Standard query 0x57dc  A ahtilenearo.ddns.net
664 2015-01-20 13:18:22.342167 DNS          80 Standard query 0x3e8c  A niesivaxumo.ddns.net
667 2015-01-20 13:18:22.558458 DNS          77 Standard query 0xd3f6  A iricilec.ddns.net
669 2015-01-20 13:18:22.783652 DNS          84 Standard query 0x734a  A uqadvoduurgeuhi.ddns.net
672 2015-01-20 13:18:22.965497 DNS          80 Standard query 0x94b1  A ehwepikeisi.ddns.net
676 2015-01-20 13:18:23.151966 DNS          80 Standard query 0xc9e9  A ehukguaggox.ddns.net
679 2015-01-20 13:18:23.335851 DNS          82 Standard query 0x292f  A onwaukfitamia.ddns.net
682 2015-01-20 13:18:23.527135 DNS          78 Standard query 0x2975  A idxoebsad.ddns.net
685 2015-01-20 13:18:23.720481 DNS          80 Standard query 0xac37  A ihneuwvaixq.ddns.net
688 2015-01-20 13:18:23.907202 DNS          84 Standard query 0x8b92  A subaukewoktalev.ddns.net
```

There are hardly any samples online that match the above DGA pattern; I only found the following four:

date	sha-256
2014-12-12	55f6945302a5baa49f32ef25425b793c
2014-12-27	e0166446a676adb9e3160c9c06e56401
2014-12-29	1ca728b9d0c64b1edfc47aeeebb899b4
2015-01-19	b75f00d7ae2857a3e1cc8f5eb4dc11b9

The earliest sample is from December 12th, 2014, which could indicate that the DGA — or at least the used configuration — is fairly new.

Configuration

The malware uses a large structure for its configuration settings, including most of the parameters that control the DGA:

```
config_data_struct struc
...
+7A8 seed_constant     ; char*
+7AC days_period       ; char*
+7B0 nr_of_domains     ; char*
+7B4 third_lvl_min_len ; char*
+7B8 third_lvl_max_len ; char*
...
```

All parameters are stored as XOR encrypted strings. The following table lists the purpose of the parameters along with the value from the examined sample. The full meaning of the parameters will become clear when discussing the individual parts of the DGA:

variable	value	purpose
seed_constant	42	A constant added to the seed. This allows for different sets of generated domains at any given point in time.
days_period	16	For how many days the DGA will produce the same domains. For example, the value 16 means the DGA produces one set of domains for the first 16 days of the month, and a new set for the second half.
nr_of_domains	64	How many different domains the DGA generates before restarting with the first domain.
third_lvl_min_len	8	How long the third level domain is at the least.
third_lvl_max_len	15	How long the third level domain is at most.

The DGA

Random Number Generator

The malware uses msvcrt's implementation of rand — a linear congruential pseudo-random number generator with multiplier 214013 and increment 2531011. The code is inlined — meaning each call to rand amounts about six lines of assembly:

```
100066CC mov ecx, [esi]
100066CE imul ecx, 343FDh
100066D4 add ecx, 269EC3h
100066DA mov [esi], ecx
...
100066E1 shr ecx, 10h
100066E4 and ecx, 7FFFh
```

In many cases the removal of the low order bytes and clipping to RAND_INT is optimized away by the compiler. For example:

```
100066CC mov ecx, [esi]
100066CE imul ecx, 343FDh
100066D4 add ecx, 269EC3h
100066DA mov [esi], ecx
...
100066E1 test ecx, 1000000h
```

In contrast to the famous Conficker.B, the rand function is used correctly and all random aspects of the DGA are truly pseudo-random.

Seed

The random number generator is seeded with the current date and a hardcoded constant:

```
10008625 call    ds:GetLocalTime ; kernel32.GetLocalTime
1000862B movzx   eax, [esp+60h+day]
10008630 xor     edx, edx
10008632 div     [esp+60h+days_period] ; is 0x10
10008636 mov     [esp+60h+domain_counter], 0
1000863E mov     edx, eax
10008640 movzx   eax, [esp+60h+month]
10008645 imul    edx, 100
10008648 add     edx, eax
1000864A movzx   eax, [esp+60h+year]
1000864F imul    edx, 10000
10008655 add     edx, [esp+60h+seed_constant] ; is 0x2A
10008659 add     eax, edx
```

which calculates:

$$ \text{seed} = \left(\left\lfloor \frac{day}{\text{days_period}} \right\rfloor \cdot 100 + \text{month} \right)\cdot 10000 + \text{year} + \text{seed_constant} $$

The configurable `seed_constant` (42 for all four samples listed in the introduction) allows for different sets of domains at the same point in time. The parameter `days_period` controls how many days the DGA will produces the same domains. For the examined sample I got `days_period = 16`, meaning the domains will change twice a month.

Third Level Domain Length

Right after the DGA is seeded, the length of the third level domain is determined:

```
10008666                 mov     ebx, [esp+60h+third_lvl_max_len]
1000866A                 sub     ebx, [esp+60h+third_lvl_min_len]
1000866E                 inc     ebx
1000866F                 jmp     short loc_10008675
10008671 ; ---------------------------------------------------------------------------
-
10008671
10008671 loc_10008671:                           ; CODE XREF:
calls_create_next_url+B00j
10008671                 mov     eax, [esp+60h+rand]
10008675
10008675 loc_10008675:                           ; CODE XREF:
calls_create_next_url+9FFj
10008675                 imul    eax, 343FDh
1000867B                 add     eax, 269EC3h
10008680                 mov     [esp+60h+rand], eax
10008684                 shr     eax, 10h
10008687                 and     eax, 7FFFh
1000868C                 xor     edx, edx
1000868E                 div     ebx
...
1000869B                 add     edx, [esp+68h+third_lvl_min_len]
1000869F                 push    edx             ; third_lvl_len
```

The above code sets the domain length to a value picked uniformly at random between `third_lvl_min_len` and `third_lvl_max_len` (including the boundaries):

```
span = third_lvl_max_len - third_lvl_min_len + 1
third_lvl_len = third_lvl_min_len + r.rand() % span
```

Generating the Domain

Next follows the core of the DGA algorith: generating the actual domain inside `create_domain`. Apart from the domain length, the subroutine also takes a type and the third and top level string as parameters.

```
10008690 mov     ecx, [esp+60h+second_and_top_lvl]
10008694 push    1               ; type
10008696 push    ecx             ; second_and_top_lvl
10008697 lea     eax, [esp+68h+rand]
1000869B add     edx, [esp+68h+third_lvl_min_len]
1000869F push    edx             ; third_lvl_len
100086A0 call    create_domain
```

The `create_domain` routine includes two similar types of DGA, selected by the `type` parameter passed to the routine. The examined sample only used type 1 to generate the domains, so I didn't investigate the other type option. The routine is rather long (over 300 lines of disassembly), which is mostly attributed to the fact that the compiler inlined `rand` and `strcat`. I therefore only show the Python version of the DGA here, you can find the underlying disassembly on Github Gist:

```
def next_domain(r, second_and_top_lvl, third_lvl_domain_len):
    letters = ["aeiouy", "bcdfghklmnpqrstvwxz"]
    domain = ""

    for i in range(third_lvl_domain_len):
        if not i % 2:
            offset_1 = 0 if r.rand() & 0x100 == 0 else 1
        s = r.rand()
        offset = (offset_1 + i) % 2
        symbols = letters[offset]
        domain += symbols[s % (len(symbols) - 1)]

    return domain + second_and_top_lvl
```

The DGA picks random letters from either *“aeiouy”* (vowels) or *“bcdfghklmnpqrstvwxz”* (consonants). The letter *“j”* is missing. Also, because of a bug in the DGA, the last characters of either character class, i.e., *“y”* or *“z”* can’t be picked. The DGA randomly choses either the vowel or consonant class for letters with even index (0, 2, 4, …); the subsequent letter is then always from the other character class. For example:

```
p <- consonant
i <- vowel

v <- consonant
u <- vowel

o <- vowel
g <- consonant

u <- vowel
s <- consonant

o <- vowel
d <- consonant

t <- consonant
o <- vowel

k <- consonant
u <- vowel
```

This will lead to domain names that are somewhat pronounceable. After the third level domain is generated, the DGA appends the configured second and top level string, for this sample “.ddns.net”

Number of Domains

The malware is very aggressive in that it doesn’t wait when it tries to resolve a NXDOMAIN, but instead immediately moves on to the next domain — first determining the length, then building the url with `create_domain`. The DGA only waits when it can either resolve a domain or if `nr_of_domains` (in my sample 64) domains are consumed:

```
10008B38 mov     ecx, [esp+60h+nr_of_domains]
10008B3C mov     cl, [eax+ecx]
10008B3F mov     [edx+ebx], cl
10008B42 inc     eax
10008B43 inc     edx
10008B44 cmp     eax, esi
10008B46 jnb     short loc_10008B5E
```

The DGA will finally sleep after all `nr_of_domains` domains are tested without success. When all domains were NXDOMAINS, the sleep time is a mere thirty seconds; If the C2 sites could not be reached for another reason (flag `dword_100393D8` set), the DGA sleeps for five minutes:

```
seg129:10008D74                 cmp     ds:dword_100393D8, 0
seg129:10008D7B                 jz      short loc_10008D8F
seg129:10008D7D                 push    300000          ; unsigned __int32
seg129:10008D82                 call    __sleep_1
seg129:10008D87                 add     esp, 4
seg129:10008D8A                 jmp     loc_10007C87
seg129:10008D8F ; -------------------------------------------------------------------
--------
seg129:10008D8F
seg129:10008D8F loc_10008D8F:
seg129:10008D8F                 push    30000           ; unsigned __int32
seg129:10008D94                 call    __sleep_1
seg129:10008D99                 add     esp, 4
seg129:10008D9C                 jmp     loc_10007C87
seg129:10008D9C calls_create_next_url endp
```

Python Code of DGA

The following Python code generates 64 domains for a given date (or today, if no date is provided):

```
import argparse
from  datetime import datetime

seed_const = 42
days_period = 16
nr_of_domains = 64
third_lvl_min_len = 8
third_lvl_max_len = 15

class Rand:

    def __init__(self, seed):
        self.seed = seed

    def rand(self):
        self.seed = (self.seed*214013 + 2531011) & 0xFFFFFFFF
        return (self.seed >> 16) & 0x7FFF


def next_domain(r, second_and_top_lvl, third_lvl_domain_len):
    letters = ["aeiouy", "bcdfghklmnpqrstvwxz"]
    domain = ""

    for i in range(third_lvl_domain_len):
        if not i % 2:
            offset_1 = 0 if r.rand() & 0x100 == 0 else 1
        s = r.rand()
        offset = (offset_1 + i) % 2
        symbols = letters[offset]
        domain += symbols[s % (len(symbols) - 1)]

    return domain + second_and_top_lvl

def dga(seed, second_and_top_lvl, nr):
    r = Rand(seed)
    for i in range(nr):
        span = third_lvl_max_len - third_lvl_min_len + 1
        third_lvl_len = third_lvl_min_len + r.rand() % span
        print(next_domain(r, second_and_top_lvl, third_lvl_len))

def create_seed(date):
    return 10000*(date.day//days_period*100 + date.month) + date.year + seed_const

if __name__=="__main__":
    parser = argparse.ArgumentParser()
    parser.add_argument("-d", "--date", help="as YYYY-mm-dd")
    args = parser.parse_args()
    date_str = args.date
    if date_str:
        date = datetime.strptime(date_str, "%Y-%m-%d")
    else:
        date = datetime.now()
    seed = create_seed(date)
    dga(seed, ".ddns.net", nr_of_domains)
```

You also find the script on GitHub Gist.

DGA Characteristics

The following table summarizes the properties of the DGA

property	value
seed	based on date and configurable constant, set to change twice a month in analysed sample
domains per seed	unlimited
tested domains	configurable, set to 64 in analysed sample
sequence	one after another, restarting with first domain when no success
wait time between domains	none, before restarting with first domain 30 second or 5 minute wait time
top and second level domain	.ddns.net
second level characters	all letters except “z”, “y” and “j”
second level domain length	uniformly distributed between configurable bounds, for the analysed sample 8 to 15 characters

Past and Upcoming Domains

For the seed constant “42” and the day period “16”, these are the first three domains generated between November of last year and the upcoming 2015.

start date	end date	first three domains
2014-11-01	2014-11-15	vitevecaasbaim.ddns.net, buxotopelah.ddns.net, doefruevtan.ddns.net
2014-11-16	2014-11-30	tevalurii.ddns.net, ufrasequcoequdi.ddns.net, qularivafou.ddns.net
2014-12-01	2014-12-15	urasahrenaheen.ddns.net, xoegfeima.ddns.net, niubsacaosuce.ddns.net

start date	end date	first three domains
2014-12-16	2014-12-31	leuvuftet.ddns.net, obneifqumea.ddns.net, bodihemouxk.ddns.net
2015-01-01	2015-01-15	uwuhuhawidb.ddns.net, exdihasuhes.ddns.net, axtoomov.ddns.net
2015-01-16	2015-01-31	pivuogusodtoku.ddns.net, onogibuluremg.ddns.net, geevheuqsemaif.ddns.net
2015-02-01	2015-02-15	obwihecidik.ddns.net, umashadilauru.ddns.net, irmatexoitn.ddns.net
2015-02-16	2015-02-28	opacutebmadufo.ddns.net, ercehuhowi.ddns.net, uwsiokxua.ddns.net
2015-03-01	2015-03-15	eqosenrealq.ddns.net, duwugunuwaqauk.ddns.net, loopowakm.ddns.net
2015-03-16	2015-03-31	efrubatoiketxa.ddns.net, loliqooq.ddns.net, tixufaheurvo.ddns.net
2015-04-01	2015-04-15	haaxicuconx.ddns.net, xaguuswibuoqope.ddns.net, ukwoubapgi.ddns.net
2015-04-16	2015-04-30	aginemkiroacus.ddns.net, haerbugoviosmu.ddns.net, vireacvio.ddns.net
2015-05-01	2015-05-15	wewateikho.ddns.net, ovicceosweub.ddns.net, siriomilfomu.ddns.net
2015-05-16	2015-05-31	vabuibofqouxog.ddns.net, tubiebikceli.ddns.net, olkaerxedus.ddns.net
2015-06-01	2015-06-15	muavosecit.ddns.net, uxefilka.ddns.net, deivekmiuwoxe.ddns.net
2015-06-16	2015-06-30	looxnaaluhotw.ddns.net, feohpoaqpeheuw.ddns.net, gabouhlat.ddns.net
2015-07-01	2015-07-15	ucsauhdune.ddns.net, deohupivoco.ddns.net, haufidasu.ddns.net
2015-07-16	2015-07-31	bovuugodvuecf.ddns.net, cuopxeudu.ddns.net, muarocavhaqe.ddns.net
2015-08-01	2015-08-15	edehgogoep.ddns.net, uciluswaaqnieb.ddns.net, ugxeicbeveudusu.ddns.net

start date	end date	first three domains
2015-08-16	2015-08-31	ogovugtuipawi.ddns.net, afowkaupbabe.ddns.net, ipkureleakm.ddns.net
2015-09-01	2015-09-15	rocaexesti.ddns.net, veonwient.ddns.net, axgoxevikupoxa.ddns.net
2015-09-16	2015-09-30	uhrixaloduuse.ddns.net, gecoohocalifluw.ddns.net, ecunxoorokonw.ddns.net
2015-10-01	2015-10-15	huosinamu.ddns.net, udebliena.ddns.net, imewgiopaqexacb.ddns.net
2015-10-16	2015-10-31	gouhumuvelcua.ddns.net, decouqunic.ddns.net, eretodweqee.ddns.net
2015-11-01	2015-11-15	hiwosoofa.ddns.net, oxacuhuvanoxxo.ddns.net, tahimoteev.ddns.net
2015-11-16	2015-11-30	vebiabipkilo.ddns.net, hunoikuxibi.ddns.net, imugoqsoakiqahi.ddns.net
2015-12-01	2015-12-15	ociqusdal.ddns.net, xiupfisuaw.ddns.net, mivibicoruq.ddns.net
2015-12-16	2015-12-31	veeswaehsisa.ddns.net, uhbacoinm.ddns.net, baugkoosdui.ddns.net