Teaching Penguins to Tell Time

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Agenda

- Why do we care?
- Hardware Clocks
- Time zones and UTC
- Network Time Protocol
- NTP and Linux on z/VM
Why care about correct time?

- For isolated systems correct time is convenient
  - Time stamps on files
  - Reliable backup and restore
  - Applications that can pick up system date and time

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MSG FROM: JOHN --DKIBHVH2 TO: NLX3951 --UITVH1 06/04/97 20:55:45
To: Rob van der Heij
From: John P. Hartmann, AIX & OpenSys, Copenhagen. JOHN at DKIBHVH2

Hi, Rob.

Next time anyone IPLs DKIBHVH2, could they also set the clock. It is now five minutes fast. That means that I rush down to the train and stand there waiting :-)

VH1 is about a couple of minutes fast.

J.
Why care about correct time?

- **Distributed applications require the “same” time**
  - File sharing (e.g. edit and make on different systems)
  - Security (e.g. Kerberos tokens)
  - Convenient for debugging and tracking

- **Most systems get the time from someone else**
  - No infinite accuracy possible
  - Required quality of clock depends on application
Who has the correct time?

- **Universal Time 1 (UT1)**
  - Computed from astronomical observations
  - Speeds up and slows down with earth rotation

- **International Atomic Time (TAI)**
  - Based on Cesium-133 radiation

- **Coordinated Universal Time (UTC)**
  - Derived from TAI
  - Adjusted to UT1 with occasional leap seconds
Daytime Protocol

- **Public Internet Service**
  - Provided by several organizations (e.g. NIST)

- **Documented in RFC 867**
  - Query to UDP or TCP port 13
  - Format of response is different per server

```bash
pipe tcpclient 192.43.244.18 13 linger 1 | deblock linend 0a | xlate a2e | cons
53108 04-04-13 10:08:46 50 0 0 432.8 UTC(NIST) *
```

- Network delay
- Clock Health (error < 5 s)
- Leap seconds
Time Zones

Standard Time Zones of the World
Time zones and UTC

- Linux system clock is in UTC
  - Number of seconds since 1970

- Local time computed from System Time
  - GNU C Runtime Library routines
  - Defined by zone info in /etc/localtime
    - Offset to UTC
    - Beginning and end of DST
Quality of Clocks

- **System clock is at best approximation of UTC**
  - Delay, jitter, offset, drift

- **High quality time keeping is expensive**
  - Trade-off between various type of error

- **Quartz controlled clocks**
  - Typical frequency offset in the range of 10’s PPM
  - Variation of several PPM due to temperature changes
  - When not corrected, may add up to seconds per day

1 ppm ~ 30 s / yr
The Ideal Broken Clock

Clock differs from true time
Constant base offset
Different frequency (skew)
Drift due to aging

Jitter
PC Clock

- **Real Time Clock with battery backup**
  - Keeps time while PC powered off
  - Cheap and not very accurate (e.g. several seconds per day off)
  - Low precision (one second)
    - Not suitable for system timing
PC Clock

- **Software Clock in Linux**
  - Initialized from the RTC during boot process
  - Incremented by timer interrupts
  - High resolution based on CPU clock frequency
    - Exploits CPU cycle counter
  - Can be adjusted through NTP
  - Used to compensate RTC drift
    - Be careful with adjusting RTC

![Graph showing time vs. error with a trend line indicating slight error growth over time.](image-url)
PC Clock

- **Software Clock in Windows**
  - Initialized from RTC during boot
  - Incremented by timer interrupts
  - Corrected frequently using RTC
  - RTC and Software Clock in local time rather than UTC
    - Complications with DST

**Dual Boot PC**

- Linux must be aware RTC is in local time
zSeries Clock

- **Hardware Time-of-Day (TOD) Clock**
  - Reasonable stable and high precision
  - Very cheap to read (STCK instruction in SIE)
  - Frequently set manually by Operator at IPL
    - Not synchronized to official time

- **Linux Software Clock**
  - Initially based on the TOD Clock
  - Even with a stable clock – wrong all day
  - Attractive to synchronize with external source
Network Time Protocol

- **Framework to synchronize clocks**
  - Defined in RFC 1305 (v3) and RFC 2030 (v4)
  - Format allows for very high precision
  - Formalizes quality of time reference
    - Stratum: Number of hops to a primary reference
    - Precision: Accuracy of the clock
  - Implementations available for many platforms
  - Many high quality public time servers
Network Time Protocol

**UDP Packet to port 123**

Contains several timestamps to compute delays and error

Timestamps in 32 + 32 bits (0.2 ns resolution)

Allows client to compute the error

Network delay is assumed to be symmetrical and constant
Network Time Protocol

- **Using the timestamps**
  - Estimate the correct time
  - Compute the maximum error

- **A proper model for the delay**
  - Interpolate time for high precision
  - Extrapolate for long term measurement
NTP on Linux

- Provisions in the kernel to adjust time
- The ntpd daemon and additional binaries
  - SuSE xntp package
  - Red Hat ntp package
  - Download from www.ntp.org
- Client configuration is trivial
  - Single entry in /etc/ntpd.conf to list the time server
  - Finding the right server is harder
Starting ntpd

- **Special adaptation mode**
  - Runs for approximately 15 minutes
  - Exchanges messages with server to adapt oscillator
  - Clock is “stepped” to approach the obtained time
  - An excessive time difference causes ntpd to panic
  - Frequency in ntp.drift maintained

```
Apr  4 12:32:07 box ntpd: ntpd startup succeeded
Apr  4 12:32:07 box ntpd[712]: ntpd 4.1.1c-rcl@1.836 Thu Feb 13 12:17:19 EST 2003 (1)
Apr  4 12:32:11 box ntpd[712]: precision = 9 usec
Apr  4 12:32:11 box ntpd[712]: kernel time discipline status 0040
Apr  4 12:40:46 box ntpd[712]: time set 311.058971 s
Apr  4 12:40:46 box ntpd[712]: synchronisation lost
```
Example of NTP setting the clock

- **Initial frequency offset during adaptation mode**
  - Taken from drift measured during earlier runs
  - Assumes clock is set by hwclock
  - For Linux on zSeries this does not hold

SuSE boot.clock broken when hardware clock not set UTC

```bash
cat /etc/sysconfig/clock
  \#
  \# Set to "-u" if your system clock is set to UTC, and to "--localtime"
  \# if your clock runs that way.
  \# HWCLOCK="-u"
```
Running ntpdate

- Correct time only available after adaptation mode
  - Not attractive for workstations
  - May be confusing for other daemons started

- SuSE runs ntpdate once during startup
  - Obtains an estimate for current time from one server
  - Time difference probably small enough to avoid stepping

Apr 14 10:12:18 linux390 ntpdate[9876]: step time server 9.61.40.85 offset 26.607496 sec
Apr 14 10:12:18 linux390 ntpd[9879]: ntpd 4.1.1@1.786 Mon Sep 29 06:44:00 UTC 2003 (1)
Apr 14 10:12:18 linux390 ntpd[9879]: precision = 22 usec
Apr 14 10:12:18 linux390 ntpd[9879]: kernel time discipline status 0040
Running ntpdate

- **Difference between Linux clock and TOD clock**
  - Initial clock stepping via ntpdate
    - Can be disabled with `XNTPD_INITIAL_NTPDATE` setting in `/etc/sysconfig/xntp`
  - Subsequent tuning of oscillator
Running ntpd

- **Normal mode**
  - Continuous exchange of messages with servers
  - Delays compared to compute frequency errors
  - Message rate lowered over time to reduce network load

```
linuxgw:~ # ntpq -p -n
remote refid   st t when poll reach   delay   offset   jitter
==============================================================================
127.127.1.0 127.127.1.0 10 l   6 64 377 0.000 0.000 0.015
+9.61.40.85 9.61.37.158 2 u  12 1024 377 15.585 1.132 100.497
+9.1.24.204 9.41.0.213 2 u  17 1024 377 104.729 0.079 313.260
*9.41.0.213 .GPS.   1 u  924 1024 377 57.036 0.898  0.185
-9.154.60.2 .hopf.   1 u 1002 1024 377 99.453  8.494 3.280
```
Example of NTP adjusting the clock

- Over time NTP will tweak frequency to get system clock close to observed true time

- You can not have it all
  - Stable clock with little jitter
  - Clock that follows true time
Example of NTP adjusting the clock

- Jump in time appears to be consistent
  - Most likely something in the network that changed delay
  - Could be related to system load
Synchronizing Linux with NTP

- **NTP works for Linux on zSeries too**
  - Keeps Linux clock close to other synchronized servers

- **Running ntpd is not for free**
  - CPU cost for idle server may increase with 50%
  - May increase memory footprint with 50%
  - Will depend on the number of time servers polled
  - Do your requirements justify the cost?

Experiment on z990

Idle: 4.1 ms/min
With ntpd 6.2 ms/min

Experiment:

Idle server 2270 pages
With ntpd 3385 pages
So how close do we get?

- **NTP keeps its own statistics**
  - The loopstats is only what NTP believes

- **How do we know what is true?**
  - The zSeries TOD wrong? Is this bad?
  - NTP getting the time wrong?

![NTP measuring the clock (PC)](chart1)

![NTP measuring clock difference](chart2)
So how close do we get?

- **Sample of a 9672 TOD clock**
  - NTP adjusted system time versus hardware TOD clock
    - Numbers as good as NTP can get
    - Not representative for all CPUs
  - In this case
    TOD clock is 4 ms/hr too slow
    100 ms / day ~ 1 ppm

![Sample of unadjusted clock](image)
Cheap way to set the clock

- **Reduce cost by setting the clock once**
  - Compensates for inaccurate set VM clock
  - Drift of zSeries TOD clock probably seconds per month

- Run ntpdate once during boot process
  - Standard code (use ntpd –q rather than ntpdate)
  - May need the –g and –x options for large adjustments
  - It does not compensate for drift
Cheap way to set the clock

- **Set the virtual machine TOD offset**
  - Can be done in PROFILE EXEC before boot
  - Isolates Linux from the details of the hardware clock
  - No adaptation phase needed, no sudden clock shift
  - With SET VTOD the TOD clock offset can be set equal to the offset of another virtual machine
    - Linux servers with identical clock
    - Clock could be read completely in user space
Cheap way to set the clock

- **Run ntpdate occasionally cron**
  - Not recommended by everyone
  - It does not compensate for drift but jumps the clock
  - May even step your clock back

- **Doing so affects global time**
  - Simultaneous requests will overload the NTP servers
  - Will be removed in the future
    - Instead use ntpd –q –x

![Clock adjust with ntpdate](image-url)
Using External Time Reference

- **IBM 9037-2**
  - Used to synchronized TOD clocks over multiple CECs in parallel sysplex
  - Can also use external reference to synchronize the clock
    - Dial-up to ACTS
    - RF receiver providing timestamp and PPS signal
  - z/VM has no explicit support for ETR but can benefit from a TOD clock kept exact

1000 Linux guests not running ntpd pays for a 9037-2
IBM 9037 Redbook

- ITSO Redbook SG24-2070
  S/390 Time Management and IBM 9037 Sysplex Timer
  - z/OS configuration
  - ETR configuration setup
Using External Time Reference

- **Use either ETR or NTP**
  - 9037 is not very subtle
  - NTP algorithms are not tuned for ETR clock steering

- **Combining NTP with ETR results in poor quality**
  - Increased swings
  - Correction overshoot
  - No improved long term stability
Using External Time Reference

- **Another example of clock quality**
  - System time driven by NTP (with 15 time servers)
  - zSeries hardware TOD clock (steered by 9037)

  - Stable drift: ~ -1 ppm
  - Correction: ~ 10 ppm
Using External Time Reference

- **Verified NTP measurements with 9037 status**
  - Jumps in the curve match the ETR dial-up times
  - Difference reported by ETR matches the measurement very well
  - 300 mS in 4 days
  - ~ 1 ppm
Conclusion

- NTP with Linux on z/VM is no silver bullet
  - Expensive to run, algorithms do not fit completely
- If you can afford some drift
  - Set the clock once during boot with ntpd -q or SET VTOD
- When clock stepping back is acceptable
  - Compensate drift by running ntpd –q via cron
- When more accurate time is necessary
  - Run ntpd as daemon to enable kernel time discipline
  - Check the hwclock issues in the boot scripts
  - Carefully select the time servers to use as reference