Increasing robustness of PTPv2 Financial networks

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(best paper award)

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Objective

- The objective of this paper is to influence the PTP revision committee to introduce multi-source robustness at the slave clocks

- To support this request, we'll describe:
  I. Latest financial regulations
  II. PTPv2 failures in Financial networks
  III. Example solution
  IV. Experimental test

About the authors

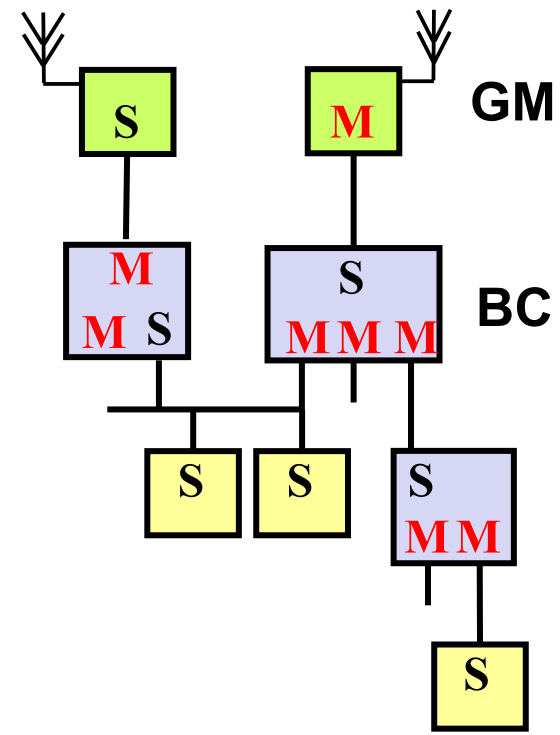
- IMC Financial Markets
  - Global liquidity provider
  - (like a currency house - but for any product)
- Deutsche Börse
  - One of the worlds largest exchange organisations
- Intercontinental Exchange
  - Exchange operator - NYSE and multiple European and US exchanges
  - Global financial market network operator

I. Latest financial regulations

- Obsolete rules:
  - Mar 1998: FINRA 7430 - *One second* against UTC, wall clocks
- Latest rules:
  - Oct 2012: UK “Foresight” committee - recommends *accurate+high resolution+synchronized* timestamps
  - Oct 2012: SEC NBBO 613.d.3 - clocks synchronized according to *industry standards*, at least *milliseconds*
  - Jul 2014: ESMA MIFID II: *microsecond accuracy, atomic clocks*

II. PTPv2 failures in Financial networks

- Eurex, August 2013
  - Active GM sent *bad* time (leap seconds = 0)
  - Backup GMs remain passive
  - Slaves jumped by 35 seconds
  - Trading halted => all customers affected



- IMC, July 2011
  - Same problem as above: <u>Single source</u>

Byzantine robustness

- There are always corner cases with a single GM; need 3 sources to absorb 1 byzantine failure
- Mathematical proof -> Failure description -> Testlab Proof

1996 - Mathematical proof
(Fetzer, Christian)

Integrating External and Internal Clock Synchronization

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June 4, 1996

Abstract

We address the problem of how to integrate fault-tolerant external and internal clock synchronization. In this paper we propose a new *external/internal* clock synchronization algorithm which provides both external and internal clock synchronization for as long as a majority of the reference time servers (servers with access to reference time) stay correct. When half or more of the reference time servers are faulty, the algorithm degrades to a fault-tolerant internal clock synchronization algorithm. We prove that at least $2F+1$ reference time servers are necessary for achieving external clock synchronization when up to F reference time servers can suffer arbitrary failures, thus the proposed algorithm provides maximum fault-tolerance. In this paper we also derive lower bounds for the best maxi-

is a granular representation of real-time and is typically provided by a standard source of time such as NIST. Clocks can be externally or internally synchronized [1]. A clock is *externally* synchronized if at any point in real-time the distance between its value and reference time is bounded by an a priori given constant called *maximum external deviation*. A set of clocks is *internally* synchronized if at any point in real-time the distance between the values of two correct clocks in the set is bounded by an a priori given constant called the *maximum internal deviation* and each clock runs within a linear envelope of real time. Externally synchronized clocks are always internally synchronized by two times the maximum external deviation, but internally synchronized clocks are not always externally synchronized.

2012 - First failure description
(Estrela, Bonebakker)

Challenges deploying PTPv2 in a Global Financial company

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***Abstract*—This paper describes the challenges encountered when deploying PTPv2 on the worldwide network of a financial company, by upgrading nearly all servers in all data-centers over a period of two years, to achieve global microsecond level accuracy between any pair.**

Acknowledging that PTP was initially designed as a LAN protocol and that all current time-keeping industry efforts are focused on PTP, the issues can be broadly divided into a) issues on the PTPv2 standard itself, b) issues that have to be addressed when PTP is expanded to work over WANs, and c) issues that caused the biggest operational impact on the (tested) implementations.

In all, this paper contributes concrete examples where PTP's byzantine robustness, scalability and efficiency characteristics range between absent to poor – and attempts to raise awareness on the steps needed to build PTP solutions with the characteristics that global users want.

I. Introduction

This paper describes the challenges encountered when deploying PTPv2 on the worldwide network of a financial company, in order to achieve microsecond level accuracy between any two servers (globally). For this, we will describe the issues discovered over the last two years, while deploying

Table I
A SUMMARY OF THE ACRONYMS USED IN THIS PAPER

ACL	Access Control Lists
BC	Boundary Clock
BMC	Best Master Clock
DC	Data-Center
FINRA	Financial Industry Regulatory Authority
GM	GrandMaster
IGMP	Internet Group Management Protocol
LAN	Local Area Network
MAN	Metropolitan Area Network
NE	Network Equipment
NIC	Network interface controller
NTP	Network Time Protocol
PIM-SM	Protocol Independent Multicast - Sparse Mode
RP	Rendezvous Point
TTL	Time To Live
UTC	Universal Coordinated Time

Taking these considerations into account, this paper divides the encountered issues into a) those that affect PTPv2 as it is defined today (i.e., for LANs), b) the issues that have to be addressed when PTP is expanded to work over WANs and c) the issues that caused the biggest operational impact on the (tested) implementations. In all, this paper attempts to raise

2014 - First proof + solution:
(Estrela, Neusuess, Owczarek)

Using a multi-source NTP watchdog to increase the robustness of PTPv2 in Financial Industry networks

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Abstract – This paper describes a fundamental single point of failure in the PTPv2 protocol that affects its robustness to failure in specific error scenarios. The architecture design of electing a single unique time source to a PTP domain – the PTP GrandMaster – makes this protocol vulnerable to byzantine failures.

Previous work has described this vulnerability from both a theoretical and practical point of view - and in particular how this affects the financial industry. This paper advances the discussion by contributing a description of the latest high-accuracy regulatory requirements on the financial industry, and by documenting new examples of failures in real-world customer-facing operations. It then describes an example of one of possible ways to increase PTP robustness while preserving its accuracy (using a multi-source NTP watchdog), and a laboratory test that shows how different protocol implementations are affected by this problem.

In all, the current paper attempts to raise awareness of the robustness requirements within the financial industry today. As only PTP is accurate enough for both current and upcoming regulatory requirements, we hope that these issues are addressed in the

fundamental single point of failure that renders this protocol vulnerable to "byzantine failures" – the worst possible class of failures where failing GMs do not shutdown, but instead start to send misleading time information to their slaves.

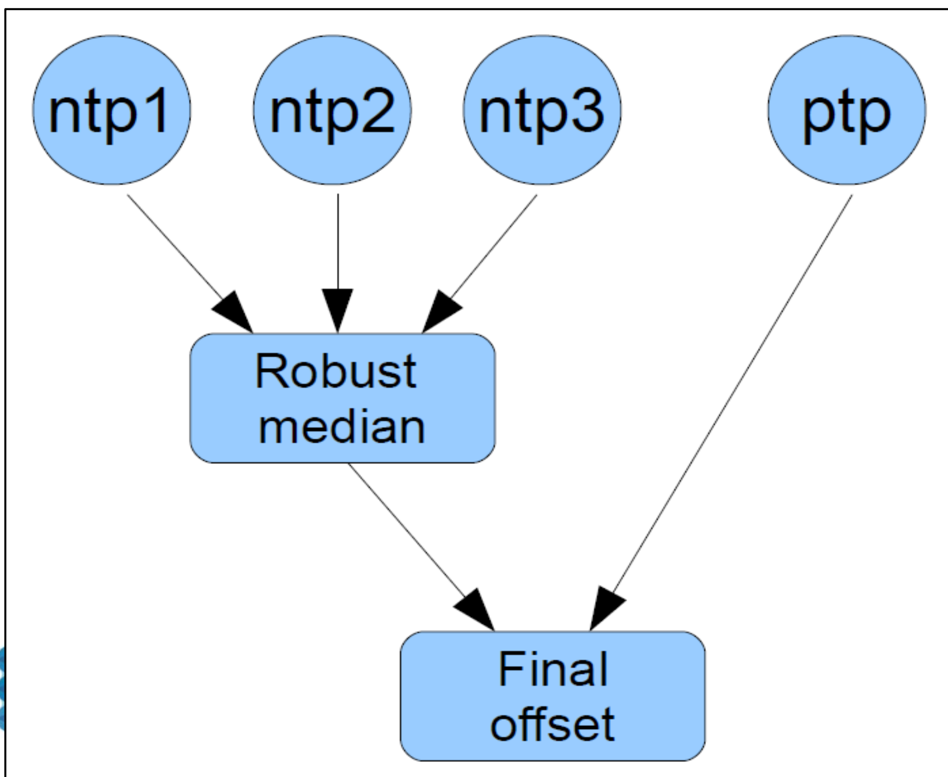
Previous work has described this exact vulnerability from both a theoretical [2] and practical point of view [3] - and in particular how this affects the financial industry [4].

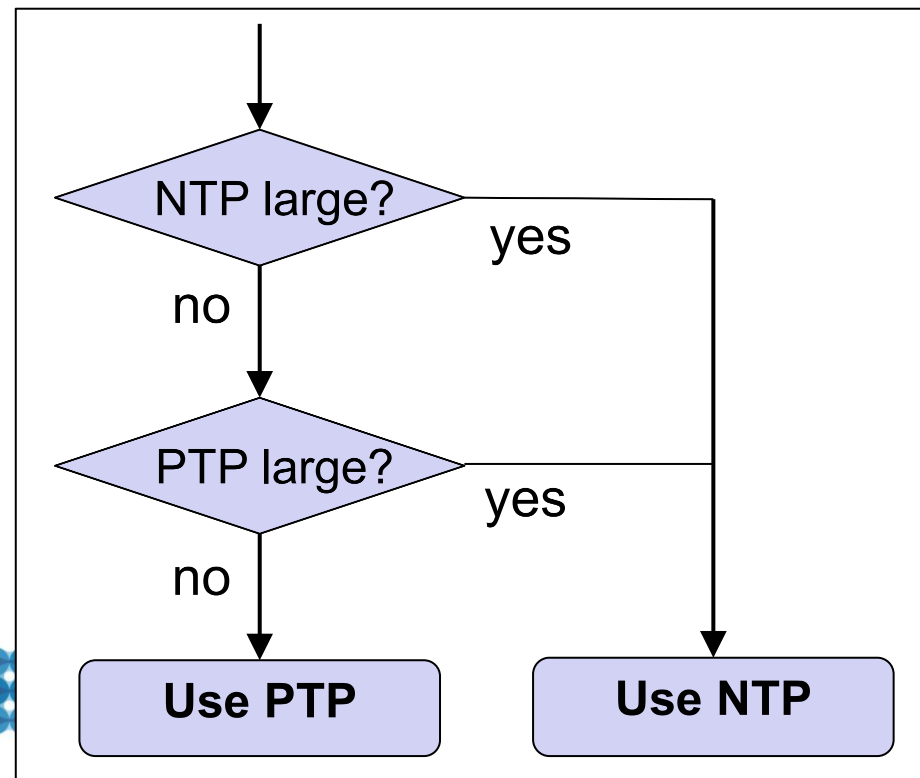
To advance the discussion, this paper makes the following contributions:

- a description of the latest regulatory requirements that are pushing higher accuracy obligations to the financial industry ([1] / [13] / [15])
- a description of new examples of failures in real-world customer-facing operations [10]
- an example of one of the possible ways to increase PTP robustness while preserving its accuracy (using a multi-source NTP watchdog to prevent failure scenarios)

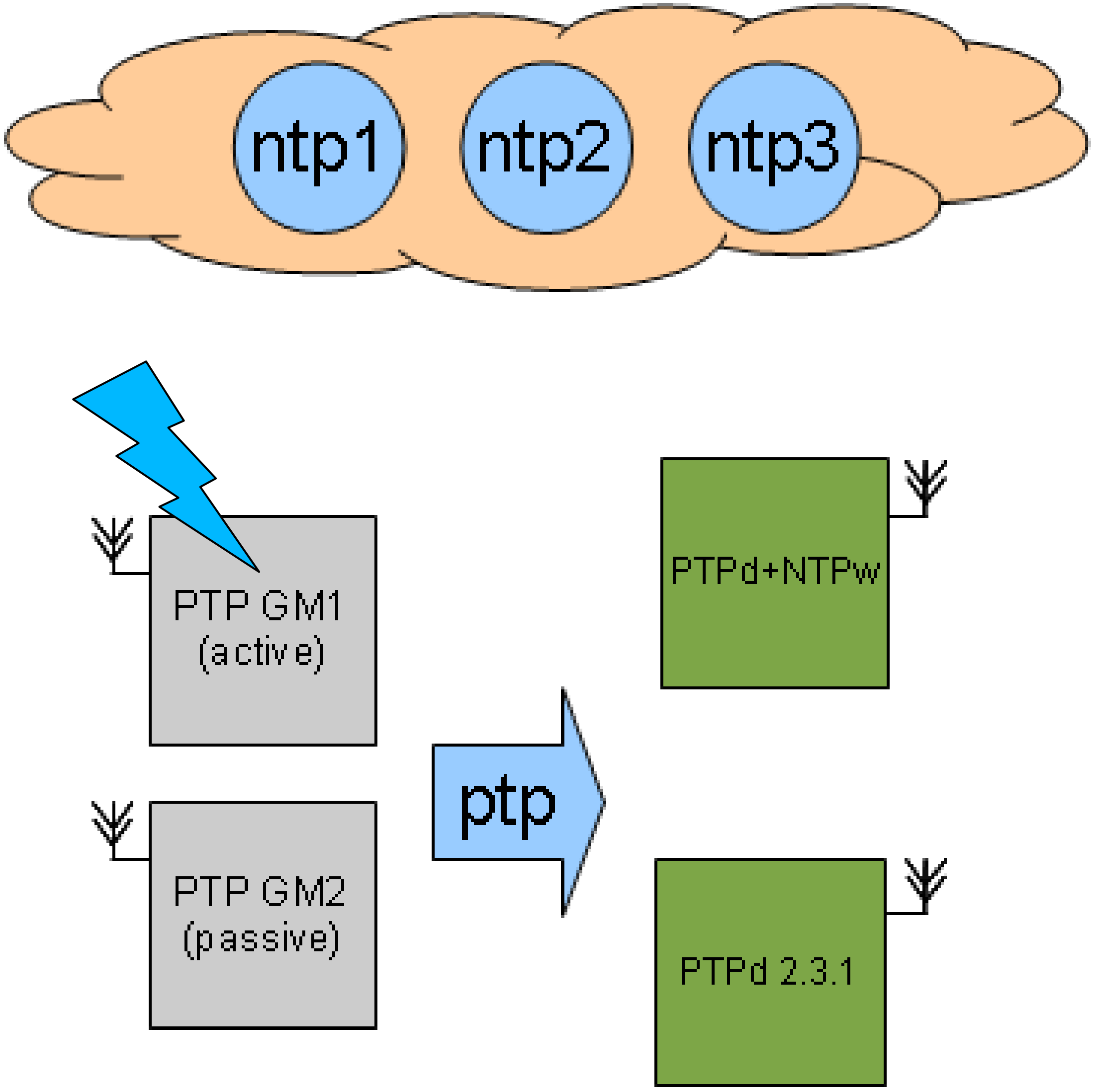
III. Solution, using with NTP watchdog

- NTP servers queried in parallel to PTP
- Robust median offset can override PTP offset:
  - -0.2 ms
  - +0.1 ms
  - +35000 ms
- PTP only touches the clock if allowed by the NTP watchdog



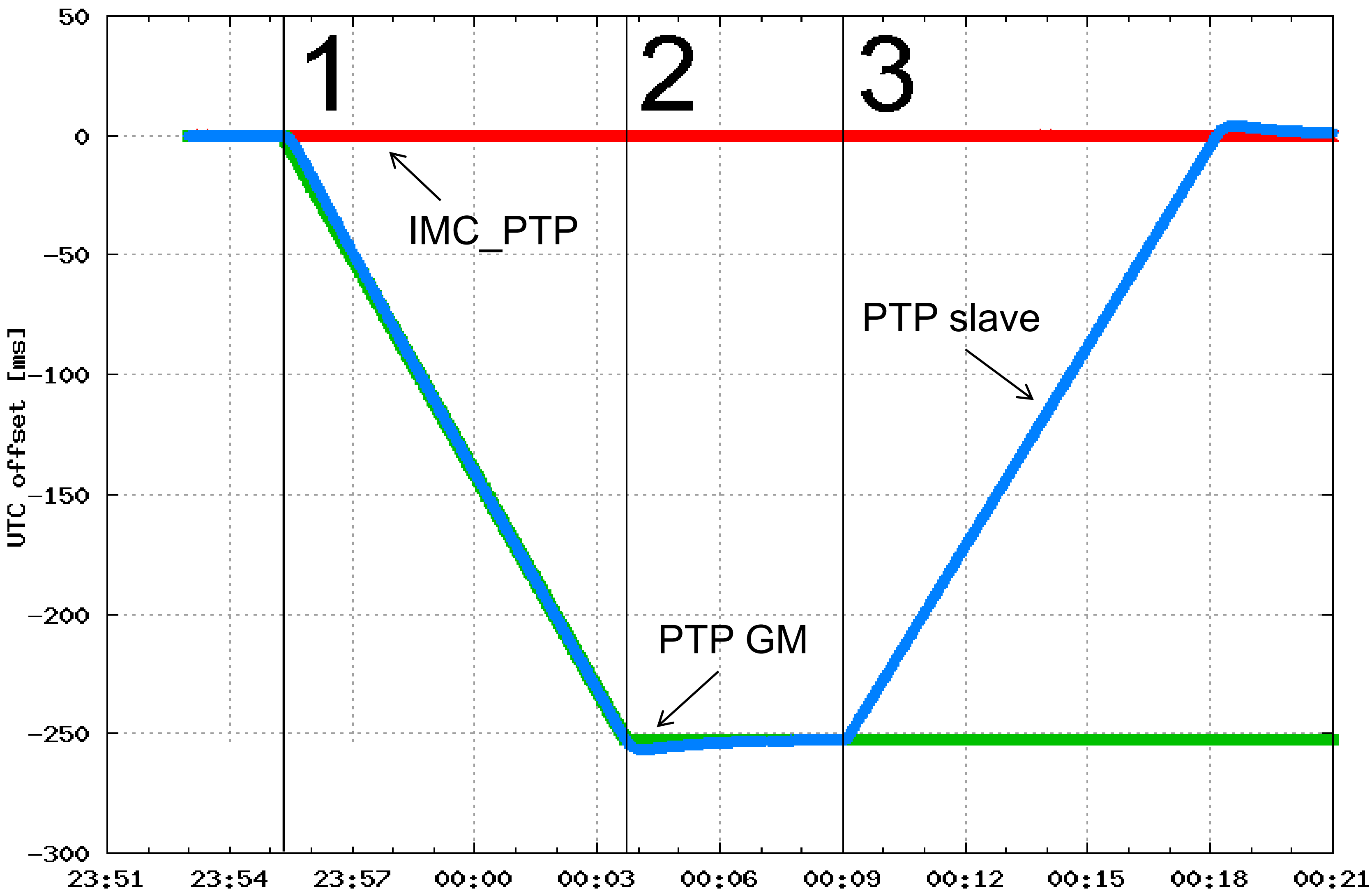


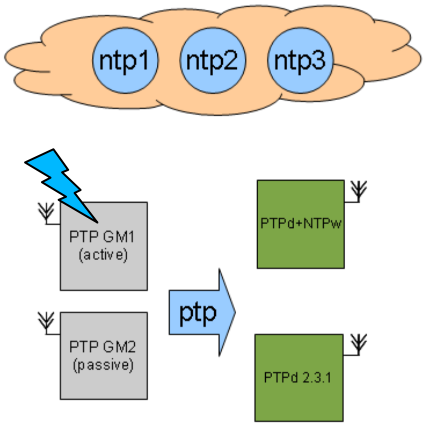
IV. Experimental testbed



Experimental results

1 - Active GM is slowed-down until 250ms UTC error
2 - Active GM returns to nominal frequency
3 - Active GM is killed





Conclusion

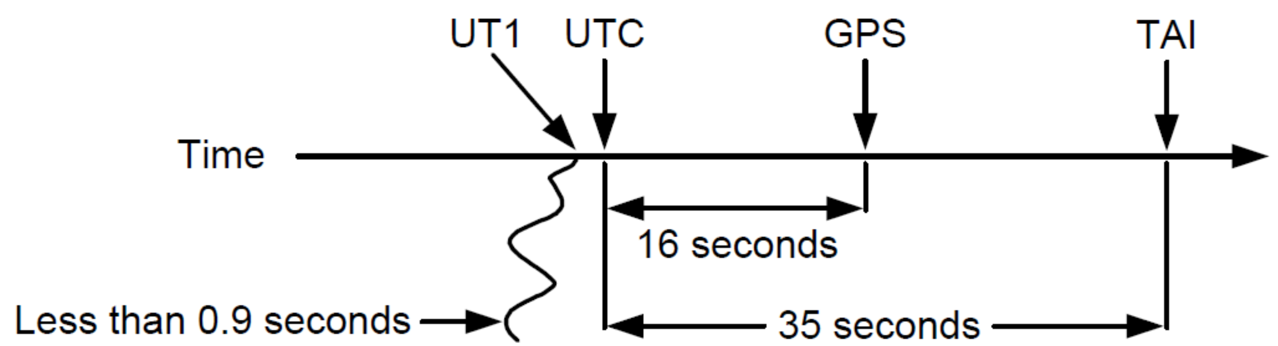
- PTPv2
  - Financial regulations require microseconds
  - PTP is the only network protocol solution to achieve this
  - PTP design has a major single point of failure problem

- PTP revision committee
  - Please add multi-source robustness to the slave clocks!

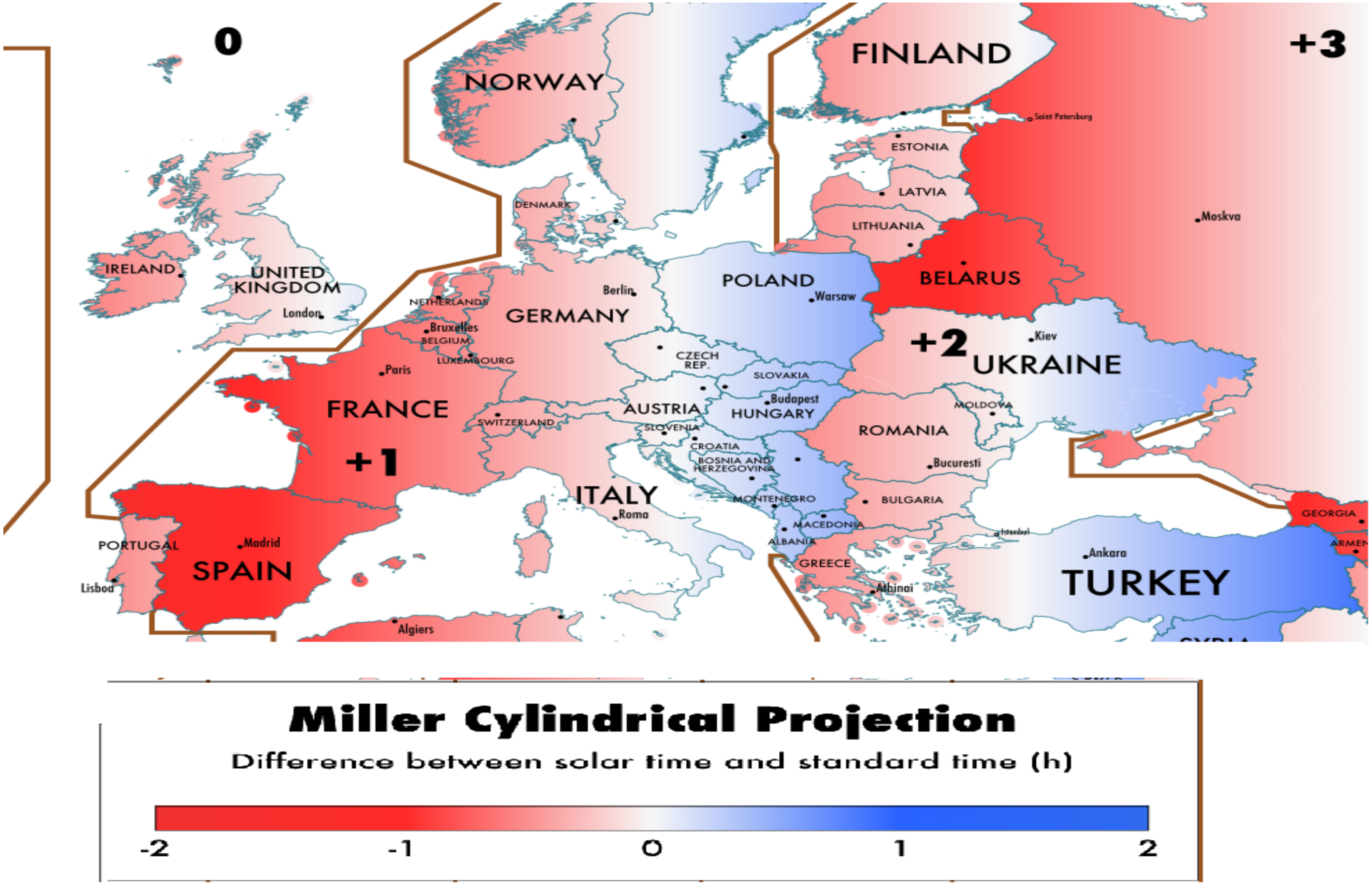
Extra Slides

Leap seconds = Problems

- Heraldsun:
  - “Leap second crashes Qantas and leaves passengers stranded”
- Cnet:
  - “Leap second bug causes site software crashes”
- Globalpost:
  - “Weird Wide Web - Leap second causes flight delays and internet problems”
- Buzzfeed:
  - “How a second brought down half the Internet”
- Wired:
  - “Leap second glitch explained”



UTC - Solar Time @ noon



Source: http://blog.poormansmath.net/the-time-it-takes-to-change-the-time

Solution 1: no “0” leap seconds

- Leap seconds != “0”
  - Earth has been slowing-down, so we’ve been adding leap seconds
  - Banning (UTC valid = “1” / UTC offset = “0”) would avoid some of the problems for hundreds, if not thousands, of years

Solution 2: Fixed Leap seconds

- Political decision
  - Recognize that “Daylight Saving Time” is a political decision

- Leap seconds = “35” forever
  - On the World RadioCommunications Conference 2015 (WRC-15), fix leap seconds to “35” forever
  - *(decision based on ITU studies happening now)*

- No Leap hour every 600 years
  - Idea: periodically, skip Daylight Savings Time for a year
  - http://old.post-gazette.com/pg/05210/545823.stm
  - http://leapsecond.com/

Solution 3: Rockets ☺

- Use rockets to control Earth’s rotation
  - Either speed up, or speed down
  - We can even use a typical PTP “PI” servo
  - Could be an easier solution than the other two ☺

Byzantine Theory recap

Allied1 Enemy Allied2