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Synchronization of Critical Infrastructures

NTP / PTP IEEE1588 GNSS Time Servers

- Financial Market (MiFID II)
- Smart-grids (IEC 61850)
- Telecom 5G (ITU-I G.8275)
- Industry 4.0 (TSN)

Network Time Synchronization

Financial Market * Smart Grids * 5G & Industry 4.0

Authors

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Microsoft Poland CEO 1992-2000

In 1985–1989 he worked as a computer consultant in the UNIDO (United Nations Industrial Development Organization) Office in Warsaw. During the period 1991–1992 he was employed in the Warsaw Olivetti office. From 1992 to 2000 General Manager of Microsoft Poland. He created the Poland-based structure of the Microsoft Corporation and was the author of the company policy during its first 8 years of existence on the Polish market. In January 2000 he received the INFOSTAR '99 Man of the Year Award in Software Business Development for his contribution to the growth of the Polish market. Vice-Chairman of the Program Committee of the 3rd Congress of Polish Information Technology. Currently an investor in the computer, real estate, and agricultural sectors. He was also active as an expert in the Interkl@sa project and contributed as an active participant of the Polish Mobile and Wireless Communications Technology Platform and the Board of the Polish Chamber of Information Technology and Telecommunications. Present and past member of the supervisory boards of several companies such as: Sport Medica S.A., MCI Management S.A., Logotec S.A., Inteliwise S.A., Ka-Na Sp. z o.o. Graduate of the Faculty of Mathematics, Informatics and Mechanics at the University of Warsaw and of the Postgraduate Foreign Trade Studies at Warsaw School of Planning and Statistics

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He holds a degree in Computer Science (Warsaw University of Technology, Poland, 1990), and degree in Economics, a Company Valuation Methods at Warsaw School of Economics 2013. The ELPROMA CEO (1992-2014) currently holding position of Member of a Supervisory Board. Synchronization solutions inventor, with over 30 years' experience in IT. He supervises NTP/PTP IEEE1588 time server line at ELPROMA getting with its R&D a couple of huge international successes including: DEMETRA Horizon 2020 Project (2014-2016) /co-developing secured UTC ground time dissemination for GALILEO/, CERN White Rabbit (2009-2014) – the next generation high accuracy PTP protocol. He contributes Facebook/NVIDIA OCP-TAP Consultant of Polish Academy od Science, Pik-Time and Thales Alenia Space contributing network synchronization for the 1st EU GALILEO receiver at Project GIANO hosted by GSA. He is a member of Atomic Time Scale Laboratories in Poland TA(PL) since 2003, and consultant for professional synchronization at financial markets MiFID II, power distribution IEC61850 and telecom 5G. Beginning from 2019 he works with Elproma team on 1st East Europe ePRTC/cnPRTC predictive high accuracy clocks.

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Time is Money

Synchronization at MiFID II

Stock Exchange & Financial Market

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Time is Money

Synchronization at Financial Market (MiFID II)

Time is Money

"Time is money" - today, this commonly known statement has gained its literal meaning for the financial sector and related IT systems. Let's try to figure out whether or not half a second is a lot. For many of us, it is a blink of an eye, but for the Italian Ministry of Finance, it is long enough to impose a tax on selected stock market transactions. The tax introduced in 2013 was imposed on automated HFT (High-Frequency Trading) operations with a portfolio holding time of less than 0.5 seconds.

Without going into details concerning Italian tax regulations, it is safe to assume that the more advanced the technology, the higher the level of constant control over HFT market by the national treasury. This short 0.5 s time may pretty soon be cut down to milli-, micro-, and even nanoseconds in the future. Allegedly, this is already being worked on at some locations. As a result, a question arises whether EU financial institutions are prepared for this and are they willing to participate in a race which to a typical citizen looks a lot like F1 car racing. In this discipline (an Olympic one nowadays), victory is determined by small fractions of billion of a second, and the competitors must be monitored on a one-by-one basis with their times measured with great accuracy.

Like in the Movie

For many years, the reliability of transmitted information has been the most important thing in IT networks and the use of computers has provided a significant speed of processing the data. Except for automation control in the industry, no attention has been paid to delays or more importantly to the need of adjusting computer clocks communicating within the local network or the Internet. Wherever transmission delay was of some significance, attempts were made to solve the problem by shortening physical connections. This is what the "*Hummingbird Project*" is about. In this movie, two visionary enthusiasts willing to build a fiber optic cable through half of USA just to stay ahead of the competition so that their stock market orders sent from Kansas are better placed in a New York Stock Exchange queue. The straight-line fiber optic was supposed to be shorter and faster, thus reducing information delays and increasing the characters' chances of financial success.

Today, stock exchanges scattered in the USA communicate with the help of special overhead microwave links located on tall towers extending way above the cities. Microwaves provide faster transmissions and the lowest delay (lower than fiber optics). In an increasing number of cases, stock exchanges launch paid, special colocation services to provide the possibility of locating your own HFT server directly in a stock exchange server room. At the same time, measures are taken to allow the investors to keep their chances balanced and their winning determined by a more advanced algorithm (the so-called Algorithmic Trading). This is why all cables and optical fibers inside the server room are properly prepared and perfectly equal with accuracy to millimeters.

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Time is Money

Synchronization at Financial Market (MiFID II)

MiFID II

Both the stock exchange and investment banks are taking rigorous steps to ensure accurate UTC (*Universal Time Coordinated*) synchronization. There exist legal regulations imposing minimum clock accuracy and network delays. The best known is the EU MiFID II directive defining synchronization accuracy and resolution levels (Attachment - Tables 1 and 2):

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0574&from=EN

The more accurate the HFT server synchronization and the lower the network transmission delays, the larger number of new opportunities to earn money on the stock exchange. This is really where time means money. Let's have a look at it on a Microsoft Corporation stock quotation example.

Trading Microsoft

Microsoft shares are listed simultaneously in New York, Tokyo, London, Frankfurt, and most probably on several other stock exchanges. Synchronized HFT server clocks located at these stock exchanges are capable of determining with great accuracy the common moment necessary to detect even the smallest fractional differences in Microsoft's quotation prices on particular floors. Taking into account these deviations, HFT robots sell shares where the Microsoft shares are more expensive and buy where the same shares are cheap, thus collecting the difference that makes up their profit. This technique is referred to as arbitrage and is investment banks' favorite additional money-making instrument, particularly because that it does not cause quantitative or qualitative changes in the investment portfolio.

However, nothing is free. Even this seemingly simple money-making mechanism involves some risks and, in specific cases, operations carried out by the bank may violate the law, e.g. when a bank uses its customer's shares to engage in arbitrage (without the customer's consent). Actions of this type are part of the dark investment side of numerous banks and belong to transactions referred to as "*dark pools*". In 2016, the U.S. Securities and Exchange Commission (SEC), in cooperation with the London Financial Supervision Commission, charged several large investment banks with several-hundred million penalties for engaging in *dark pool* investments. As a result, to remain transparent, both the investment banks and the stock exchanges themselves are implementing the latest synchronization technologies offering an accuracy level of billionths of a second (nanoseconds).

High-accuracy synchronization means an increase in the frequency of purchases and sales of shares which in turn generate quota trading at the right volume, thus providing tangible benefits to the players, the stock market, and even the treasury. Arguments that emphasize the advantage of an investment of this type is regarded as the reduction of the influence of one's behavior (panic-voracity). Injustice and lack of opportunities for a human to fight the algorithm and the machine are most often pointed out amongst disadvantages. "For and against" discussions and polemics are taking place and will be continued.

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Time is Money

Synchronization at Financial Market (MiFID II)

Robust Synchronization Time as a Service

The HFT market is constantly growing together with new financial services and IT products. Even a "Time as a Service" synchronization service has emerged. Today, the "Time as a Service" is offered by numerous stock exchanges worldwide; however, the first one was the London LSE, which is sometimes supported by the renowned London NPL – the National Physical Laboratory, the same one where the meritorious computer pioneer Alan Turing, used to work. The NPL Laboratory is the National Metrology Institute of UK and it provides the UTC reference pattern with a maximum error of nanoseconds via Ethernet. The time comes from the top-class cesium atomic clocks available to the NPL laboratory and used in its everyday work.

The UTC(NPL) time differs from the UTC provided via the GPS satellite system. It is relevant to know that despite its "universality", the UTC is not so “universal”. This is because each country generates it independently and autonomously based on its atomic clocks. Therefore, while this US UTC is associated with the USNO Laboratory, the UTC(NPL) is created in London. The differences are small, but compared, for example, to GLONASS Russian satellite, they can reach up to 30-40 ns, which is quite a lot for some infrastructures. While we are talking about national time, it is worth mentioning that other EU members have a very good quality UTC(k) scale generated under the supervision of the local Central Office of Measures and they are ready to support local Stock Exchanges too.

But, coming back to the avant-garde of the world of finance, "Time as a Service" is a new model of selling “legal time” and synchronization for which every modern state in the age of digitalization is getting ready. Inside EU the GALILEO is becoming to play important standardization role for synchronization for industry. The financial sector is not the only place where precise synchronization is important. While entering the era of the so-called "Industry 4.0", it seems misleading to think of it as just an advertising slogan. A new network architecture, TSN (Time-Sensitive Networking), altering the optimization paradigm is unnoticeably emerging. TSN networks introduce priority management, and this requires precise synchronization of each element (industry sensor, computer … etc.) of this type of network. However, we will write about this subject in the next episodes of our series.

So, let us not smile when the enthusiasts of this topic talk about nanoseconds, as such intervals will soon accompany us in our everyday life. Perhaps, it would be more beneficial to teach more than just "mile" or "micro" prefixes in schools. Perhaps, it's time for "nano" or even "pico".

Time & Energy

Will the future power industry be safe?

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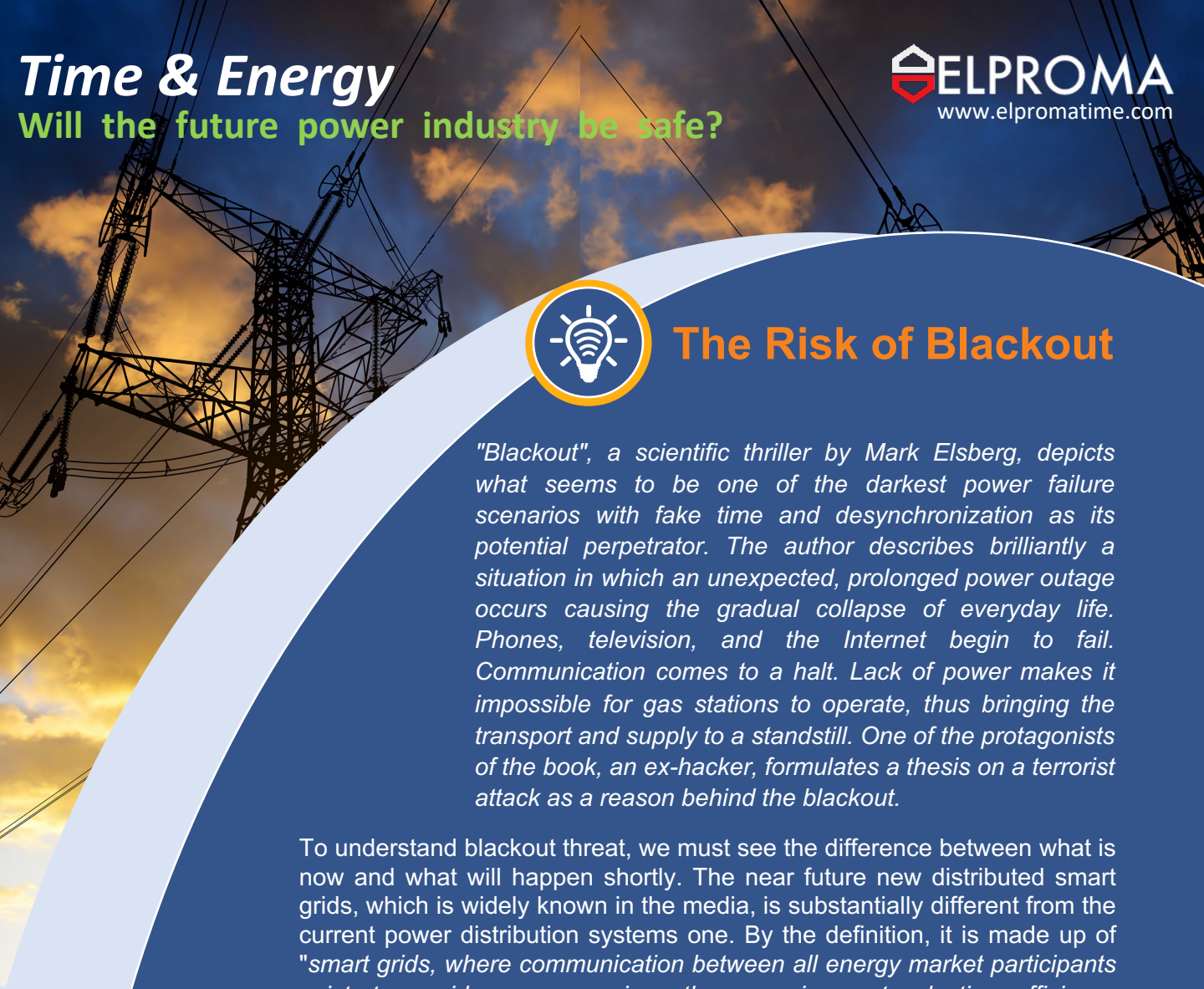

The Risk of Blackout

"Blackout", a scientific thriller by Mark Elsberg, depicts what seems to be one of the darkest power failure scenarios with fake time and desynchronization as its potential perpetrator. The author describes brilliantly a situation in which an unexpected, prolonged power outage occurs causing the gradual collapse of everyday life. Phones, television, and the Internet begin to fail. Communication comes to a halt. Lack of power makes it impossible for gas stations to operate, thus bringing the transport and supply to a standstill. One of the protagonists of the book, an ex-hacker, formulates a thesis on a terrorist attack as a reason behind the blackout.

To understand blackout threat, we must see the difference between what is now and what will happen shortly. The near future new distributed smart grids, which is widely known in the media, is substantially different from the current power distribution systems one. By the definition, it is made up of "*smart grids, where communication between all energy market participants exists to provide energy services, thus ensuring cost reduction, efficiency improvement, and integration of distributed energy sources, including renewable energy*." It brings along numerous advantages but requires a very solid and robust synchronization infrastructure foundation so that we do not allow the better to be the enemy of the good. Critical attributes ensuring smart grid stability include the exact time, stable frequency and theirs highly accurate synchronization.

Smart-grids vs Classical Power Distribution

When it comes to the traditional power industry, electricity is generated by a power plant (the production), distributed by an operator (the distribution), and finally, it's us (the consumers). One-way power supply to homes and plants has worked out perfectly well for over a hundred years; today, however, it is no longer enough. The developing economy necessitates a growing electricity demand. Infrastructure development related restrictions are also emerging. A discussion of solutions is hindered by the need to protect the environment, which is to serve future generations.

Fortunately, what we are witnessing are changes and transition of the power industry to a new era of Industry 4.0. Today, photovoltaic panels are installed on roofs, we see a growing number of landscapes filled with a wind turbine or biogas plants. These new sources allow us to increase the pool of energy to be used by society.

The primary role of standard power plants will be reduced in the intelligent distributed power industry of the future, Electricity will be generated simultaneously by multiple equivalent plants. These "power plants" will undoubtedly be located at great distances from each other. Contrary to modern distribution, electricity will have to be transmitted bi-directionally and these directions will change over time on a dynamic basis. Principles similar to railroad traffic management will apply here with the difference being that the equivalents of the "switches" must be switched simultaneously on both sides of the "track" with an accuracy of a millionth of a second (microsecond, 1μs). This operation is carried out by IED (*Intelligent Electronic Device*) relays – - the switches. It's challenging Elproma NTS-5000 (www.elpromatime.com) grandmasters to nanoseconds to appoint IEEE C37.238 and IEC61850 norms.

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The accuracy of 1μs for IEEE C37.238, IEC61850

Why is the 1μs accuracy of such great significance? A longer interval leaves the transmission line open for too long, causing a power outage. Since there are a lot of simultaneous power producers and consumers in a smart grid, time and synchronization of IEDs relay switches are particularly important. In addition to local deficiencies, mismanagement may lead to undesirable accumulation of surplus energy. Energy management will be based on balancing energy surplus and deficiency. Extreme levels of these parameters may trigger safeguards leading to an uncontrolled domino effect of failure that may even result in a blackout. There can be neither too much nor too little energy in the system. The network must always contain "just the right" amount of energy which itself is seamless and time-varying. Smart grid control will probably focus on minimizing the losses and maximizing the efficiency of power transmission (active power vs. reactive power). This goal is achieved both through the ability to make a precise impact on the efficiency of current generating sources (e.g. one can either slow down or periodically switch off wind turbines to ensure protection against energy surplus), and through the dynamics of changes in power distribution line connections paths completed with the use of IEDs. Therefore, to make the right decisions one should the actual condition, a definite piece of information "here and now" - both on the local and remote levels.

Phasor Measurement Units (PMU) equipped with local clocks are used to measure the status of the current. As in the case of IEDs. i.e. connection setup devices. The system monitoring process assumes that the post-filtering information (e.g. data arriving with an unacceptable delay) is very likely to reflect the actual energy condition. On this basis, the control station extrapolates the situation at the next moment in the future by issuing line control instructions to the IED. This is how time-varying variable, dynamic power transmission structure in the smart grid, the stability of which depends on time and synchronization.

Note: https://www.gsa.europa.eu/newsroom/news/demetra-delivers-dividends-elproma

As the results of DEMETRA Project 2015-2016, Elproma has developed new range of PTP servers for smart-grids including NTS-5000 grandmaster and new NTS-pico3 family of slave time servers.

Until quite recently, it was thought that synchronization would be ensured by a GPS (or other GNSS) system. However, it turned out that jamming the GPS signal is not that big of a challenge and can be completed with the help of inexpensive, so-called jammers available widely across the Internet. One may also falsify the GPS signal by substituting his own time and position data. This technique is called "*spoofing*" and it forms a particular risk to the smart grid energy industry since jamming can be counteracted while spoofing is not so easy to identify and fight. Effective spoofing results in a miscalculation of delays of PMU data incoming via a computer network. This will generate unwanted rejection of the correct information and incorrect acceptance of the bits of information traveling too long. Consequently, energy mismanagement will exist that may cause a failure or even a blackout. Loss of the true chronology of events in the LOGs due to desynchronization will become an additional problem. This, in turn, will make it impossible to identify the problem because as it will disturb the logic during the analysis process. In desynchronized LOGs, one may observe a strange phenomenon in which "the effect precedes its cause."

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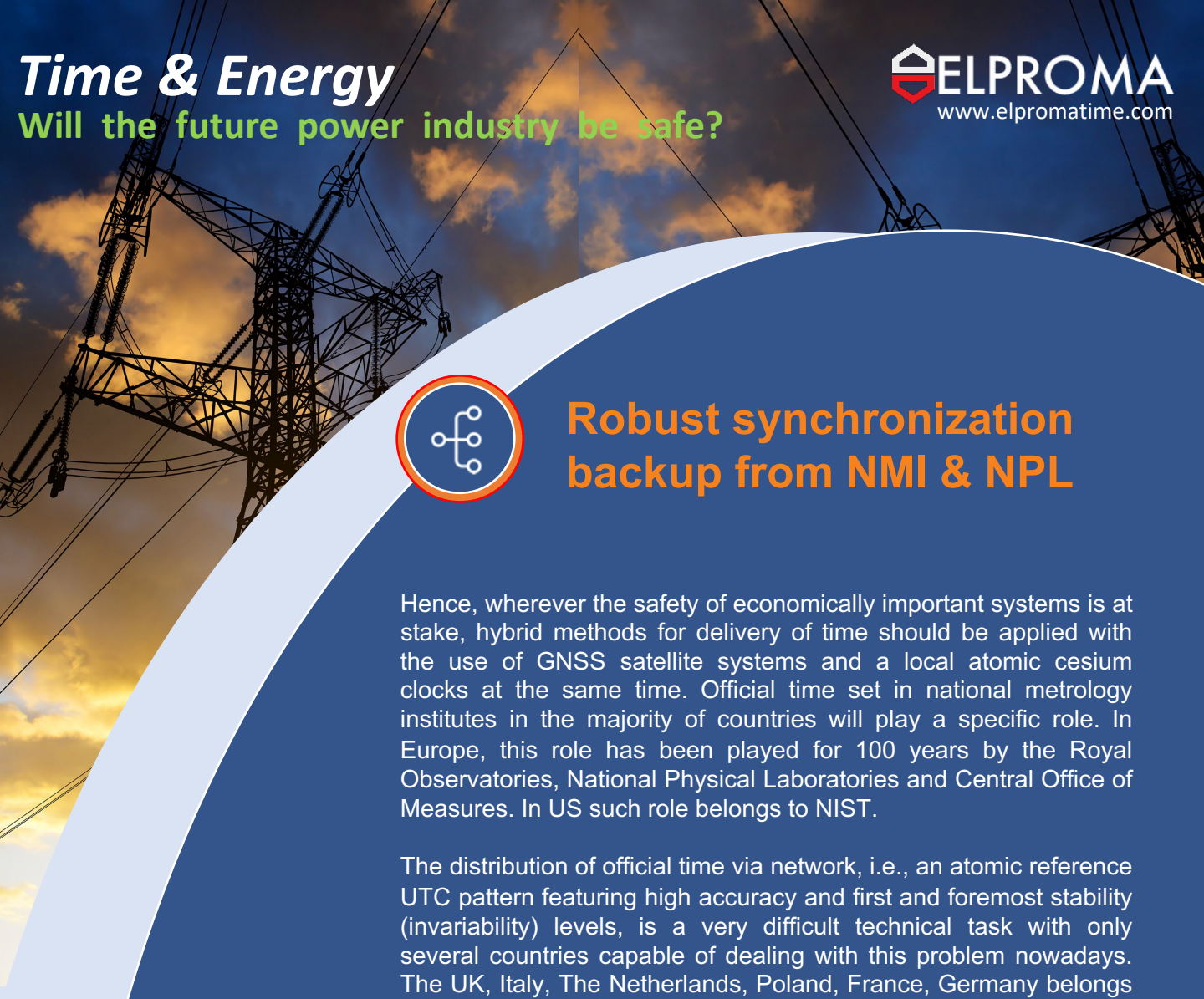

Robust synchronization backup from NMI & NPL

Hence, wherever the safety of economically important systems is at stake, hybrid methods for delivery of time should be applied with the use of GNSS satellite systems and a local atomic cesium clocks at the same time. Official time set in national metrology institutes in the majority of countries will play a specific role. In Europe, this role has been played for 100 years by the Royal Observatories, National Physical Laboratories and Central Office of Measures. In US such role belongs to NIST.

The distribution of official time via network, i.e., an atomic reference UTC pattern featuring high accuracy and first and foremost stability (invariability) levels, is a very difficult technical task with only several countries capable of dealing with this problem nowadays. The UK, Italy, The Netherlands, Poland, France, Germany belongs to a group of well-prepared European countries. The dissemination of the national time scale UTC(k) is nowadays more frequently than ever before. Finally, the EU GALILEO is slowly acting EU official time reference that together with GPS and national UTC(k) network time distribution with special time auditing facility creates new powerful and robust synchronization reference for smart-grids.

It is believed that the native power industry evolving towards smart grids will rely on this solid foundation of time and frequency. The main and regional systems must be protected tamper-proof and protected against external interferences – the time and synchronization must be safe.

Finally, let's go back to the classic power industry and try to figure out if and where it requires accurate time and synchronization. Today, the most important place where synchronization is required is the classical generator turbines. They must rotate simultaneously – precisely 50 times per second – to generate 50Hz AC voltage.

Moreover, accurate time is needed to supervise the distribution and automated readouts (the so-called a smart metering) and measurement processes. Time is also used by billing and automatic point location systems on high wear and tear lines and high transmission line interruption risk. However, in these cases, there is no need for synchronization with high accuracy. Although no high-accuracy synchronization is needed in the aforementioned cases, the Industry 4.0 smart grid power generation will require the provision of an identical time pattern over an extensive (the so-called the time domain) area to allow each distributed, equivalent power source to generate 50Hz AC voltage. This frequency is defined by a technical standard documents and protected by law. For this reason, we would like to re-emphasize the current and future important role of time and National Measure Institutes providing official UTC time.

Time & Telecom 5G

Synchronization at Industry 4.0

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Telecom 5G & Industry 4.0

Time in Telecom 5G & Industry 4.0

As a result of the appearance of smartphones and smartwatches, the need to adjust watches has disappeared. By trusting the technology, we got used to the automatic synchronization of time and date with the GSM mobile network. That is why the view of mobile phones lying next to each other, logged in to various operators, where we see a different time on their displays, is so surprising. How can we trust such time information?

While minute discrepancies are not of great importance to humans, they create a problem for industry as it enters the automated economy of the future. There are many reasons of differences in time between operators, but they must disappear before final Industry 4.0 becomes fully dependent on 5G solutions. The safety and satisfaction of users of the latest technologies will depend on it. In Industry 4.0, the dependencies between the producer, supplier and recipient create an "intelligent" ecosystem, based on the prediction of future events, good and bad ones, and allowing to implement optimization or substitute procedures "on time". This is area where the trendy terms Big Data, Machine Learning (ML) and Artificial Intelligence (AI) meet today, and the guarantee of correct and stable operation of all this automation will be time and the synchronization.

The 2G/3G vs Lte 4G synchronization

In 2G/3G telecommunication, apart from ensuring the chronology of system event recording (LOG) and ignoring the role of time and date in billing systems, there was no need for precise synchronization. In the old telecommunications, frequency was important because it was necessary to maintain the stability of the radio network transmission channels - these in turn influenced the efficiency (bandwidth) and, consequently, the quality of service. But it was only like a second hand on a clock that had no minute or hour hands. If there were effects such as echoing own user's voice during a call, dropping connections or data transmission while traveling, they were most likely the result of insufficient harmonization of distributed base stations (BTS) and telecommunications devices.

The situation improved with the appearance of 4G/LTE. Telecoms have significantly improved timing by installing time-referenced satellite receivers at the nodes and BTSs. Unfortunately, it turned out that the problems related to satellites reported in the media more and more often resulted in inconsistencies in the time indications between operators, and it even happened that they differentiated it within the network of one company. And yet the clock on the phone usually indicates the time downloaded from the nearest BTS access point.

Maintaining Time Domain

It also turns out that satellite time is not universal and depends on a specific GNSS system (Global Navigation Satellite System), and on a specific receiver, i.e. the manufacturer, model and sometimes the firmware version. The differences are not large, but for example the 30-40 nanosecond discrepancy between the American GPS and the Russian GLONASS is a significant complication for 5G telephony and, consequently, for Industry 4.0. The Chinas BEIDOU operates 4-5ns near GPS and GALILEO and this is suitable for 5G.

It is true that GSM operators also have their own atomic clocks, and this would suggest that the issue of time compliance should resolve itself automatically. Unfortunately, this is not the case, because the pattern does not always reach the place where the user's phone logs on. Even if the atomic clock readings reached the entire infrastructure, the problem would still remain, although to a lesser extent. Atomic clocks are stable, lagging behind or accelerating 1 second every few hundred years, but they only have a substitute for a second hand. Setting up the remaining ”clock pointers" and the calendar still requires the GNSS.

Without time compliance over a large area, it becomes impossible to fine tune the radio bands or manage the transmission channels. This could be solved by introducing additional security, but it would be at the expense of bandwidth, purchased for a lot of money. As a consequence, performance would decrease, and instability would decrease the transmission speed and the number of concurrently served subscribers, including M2M wireless telemetry devices. Therefore, in 5G telecommunications, very accurate synchronization at the level of millionths of a second (1 μs) is required. From synchronization devices, e.g. PTP IEEE1588 servers produced by the Polish Elproma (www.elpromatime.com), accuracy reaching even billions of fractions of a second – - nanoseconds (1 ns) is expected. The native apparatus is considered to be one of the best and valued in the world. It is also better suited to local threats and geopolitical situation. This fact is important in terms of cybersecurity of a telecommunications company, as it is known that sometimes GNSS can be manipulated and destabilized. For example, in many countries, the use of private GSM repeaters can be dangerous for the cell network itself and is legally limited, not least when we are dealing with professional jamming of specific GNSS signals. In the case of infrastructure based on GNSS, attack and spoofing of the satellite signal are also possible).

The public awareness is also missing rare but dangerous failures of entire satellite systems that can destabilize not only 5G, but also directly affect the functioning of the industry. The most dangerous are also internal disturbances, such as the one of 01/26/2016, known as satellite problem no. 23 - SVN23 (https://www.itnews.com.au/news/satellite-failure-caused-global-gps-timing-anomaly-414237), which introduced a 13.5 microsecond error to the entire GPS for many hours. Such large false readings may cause a loss of synchronization, which will disrupt the stability of operation of critical structures from telecommunications, through the energy sector, to the stock exchange and financial sector. When discussing the issue of threats, it should also be remembered that, with the exception of the European GALILEO, all other systems, i.e. the American GPS, Russian GLONASS, Chinese BEIDOU, Indian IRNSS, are military infrastructure that cannot provide global services in a crisis situations but they can support their local industry well.

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Telecom 5G & Industry 4.0

Backup Time Centers TaaS – Time as a Service

Therefore, for several years, in many countries, dedicated backup time centres have been built more and more often. They are an alternative source of time for satellites. After connecting to the centre with optical fibres, users, incl. 5G operators (and through them the beneficiaries of Industry 4.0), energy smart-grids or financial institutions receive the caesium atomic time standard in the form of time-as-a-service (TaaS - Time-as-a-Service). It replaces or supports an infrastructure that is heavily dependent on GNSS today and uses the satellite pattern for the current synchronization. Such paid services are already launched in the USA and United Kindgom (e.g. London NPL, US NIST), and implementation works are underway in other EU countries too.

Synchronization in the TaaS service today is done using the Precision Time Protocol PTP IEEE1588, but previously NTP (Network Time Protocol) was well used and it is still present in every computer today. The great achievement of NTP was that it combined Unix, BSD, Netware, Linux, OSX, Apple OS/iOS and Microsoft Windows standards, the PTP protocol provided amazing synchronization accuracy by connecting the largest server rooms and data centres of infrastructures supporting CLOUD/EDGE/FOG computing, including Microsoft Azure. Both NTP/ PTP solutions are similar in theory of operation and you can discuss their advantages and disadvantages.

The limitation of PTP is its use in local LAN/WAN networks and no operation on the Internet. The advantage is a much better synchronization accuracy, which is not so much due to the protocol itself, but due to its relationship to the network card. As a consequence of the integration, it is possible to take into account (calibrate) the internal delays. The proofreading is low level and is called in technical slang hardware tagging time or a hardware time-stamping. Thanks to this, the precision reaches the level of nanoseconds (billionths of a second). These days a new proposal from Siemens is coming that improves old NTP by improving std. accuracy x10 and x100.

But the timing record belongs to the White Rabbit technology from CERN operating at the picosecond (trillionth of a second) level. However, it is not only a success of Swiss watchmakers (CERN is in Switzerland), but also a significant Polish & Spanish contribution to the world synchronization technology. The White Rabbit (WR) is one of the characters of Alice in Wonderland, the one who, meeting Alice, having problems with punctuality, takes her into Wonderland. The protocol was co-created in the initial phase by, among others graduates of the Warsaw University of Technology Tomasz Wlostowski (CERN), Grzegorz Daniluk (Elproma, now CERN), Maciej Lipinski (CERN), with the participation of Elproma. Tomasz Widomski (ELPROMA) initially took up the difficult challenge of introducing the protocol at PTTI/ION in 2012: https://elpromatime.com/wp-content/uploads/2018/10/PTTI-2011-White-Rabbit.pdf

The WR, initially promising to be an imminent success, unfortunately lagged behind in the standardization process. Only in May 2020, the protocol received standardization and was included in the PTP IEEE1588: 2019 standard. The protocol was used during the DEMETRA Hozrizon2020 project. Perhaps this is the direction the 5G core synchronization needs to take into account considering robust synchronization for 5G deployments.

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