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THE FUTURE INTERNET – PROBLEMS AND PERSPECTIVES

The issues of the current Internet architecture considered. A brief survey of related publications given. The perspectives of migration to the Future Internet discussed. Cognitive principles formulated for study Internet as a complex system. An author's vision of the Future Internet outlined. Primary steps proposed to reorganize the IP layer in TCP/IP model when transition to the Future Internet architecture. Figs.: 1, Refs.: 24 titles.

Keywords: future Internet architecture; system approach; TCP/IP.

1. Introduction. The problem statement. Today, the Internet so deeply penetrates our live that one cannot imagine activities without it. It may seem that further development of network technologies is limited by nothing but the efforts of researchers and engineers. Nevertheless, among the experts understanding is gradually growing that modern Internet not fundamentally changed since its creation five decades ago. Its visible rapid development mainly affected the edge floors of network architecture, i.e. communication channels capacity increased and plenty on-top-IP applications emerged. The Internet itself as communication media for client processes interaction, remains doing nothing but unreliable IP-packet delivery. The so-called "transport protocols" TCP and UDP, which provide reliable message transportation over the Internet infrastructure, are not truly embedded into the Internet body itself (communication channels, switches, routers); instead, these "transport protocols" are realized by operation systems of user's terminal devices. Of course, a lot has changed also in medium layers of Internet construction, yet many innovations looked like more "patches" added in legacy architecture to withstand increasing loads. Actually, such patch-made improvements do not deeply advance the foundations of the Internet. This resulted in multitude overlapping protocols emerging, along with increasing complexity of the overall Internet framework. The Internet is getting hard understand and manage. Much efforts in further progress the Internet become less commensurate with that small improvements which can be achieved hereby.

This work aims to contribute in core aspects researches of the current Internet, and the perspectives of migration to future Internet.

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2. The Internet background. The modern Internet is often referred to as "Network of Networks", where "networks" constituting the "Internet network" are separate independent Autonomous Systems (AS). The Internet now embraces thousands of interconnected AS. The United States of America (in particular, Advanced Research Projects Agency ARPA of the USA Department of Defense), is the birthplace of the contemporary Internet. ARPA was created in 1958 in response to the launch by the Soviet Union of the world's first artificial earth satellite (1957). The ARPA agency after its creation changed its original name three times more: ARPA (1958) – DARPA, or Defense Advanced Research Projects Agency (1972), - ARPA (1993) - DARPA (1996). The ARPA specialists were given the task to maintain the forefront of US military technology facing the threat of third world war. One of the main tasks of ARPA in the 60-70s was to sponsor the development of a distributed computer network between the largest research centers and universities in the United States and Great Britain. This network, dubbed ARPANET, become the forerunner of the modern Internet. Later, ARPA (DARPA) sponsored developments in the Unix operating system and the BSD (Berkeley University) version of the TCP/IP protocol suit, which became the foundation of the Internet.

Today, DARPA unites 6 main structural divisions, and continues to actively sponsor basic research and projects in the field of information and telecommunication technologies, physics, mathematics and other areas of strategic importance for the USA and NATO countries. One of the most significant first results of the ARPA activity was creation of the ARPANET packet network – the predecessor of the modern Internet. A detailed history of these and subsequent events was described by one of the ARPANET ideology creators L. Kleinrock (American scientist and inventor, 1934) in his book on the history of the Internet. In particular, he wrote: "On June 3, 1968, the ARPANET Program Plan was formally submitted to ARPA by Roberts, and it was approved on June 21, 1968. The ARPANET procurement process was now officially underway" (M. Schwartz, L. Kleinrock. An early history of the Internet, page 29, [1]).

However, the informal "birth date" of the Internet is often associated with a later event – October 29, 1969. At that day, the first digital message transmission happened from UCLA University computer in Los Angeles to the SRI Research Center computer in Stanford. Then only the first two letters of the word "login" were successfully sent and confirmed by remote receiving party in Stanford. After on, computer connection dropped. But this event became a historical fact, after which the ARPANET network was created at an accelerated pace ([1], p. 32).

3. Related publications survey. This section gives a brief overview of publications on "Future Internet". We begin with D. Talbot article "The Internet is Broken", ([2], 2005). This article consistently analyzes scientific publications of David Clark, who is the main architect of TCP/IP suite. At that time, a widespread adoption of Internet technologies only began, however, D. Clark yet concluded that Internet project had already near to collapse. He wrote: "The Net's basic flaws cost firms billions, impede innovation, and threaten national security. It's time for a clean-slate approach... Things get worse slowly. People adjust... The problem is assigning the correct degree of fear to distant elephants... Internet has wrought wonders... and critical industries like banking increasingly rely on it... At the same time, the Internet's shortcomings have resulted in plunging security and a decreased ability to accommodate new technologies. We are at an inflection point, a revolution point... We might just be at the point where the utility of the Internet stalls - and perhaps turns downward" [2].

D. Clark claimed next: "The result is that the originally simple communications technology has become a complex and convoluted affair. For all of the Internet's wonders, it is also difficult to manage and more fragile with each passing day... It's time to rethink the Internet's basic architecture, to potentially start over with a fresh design – and equally important, with a plausible strategy for proving the design's viability, so that it stands a chance of implementation. It's not as if there is some killer technology at the protocol or network level that we somehow failed to include... We need to take all the technologies we already know and fit them together so that we get a different overall system. This is not about building a technology innovation that changes the world but about architecture – pulling the pieces together in a different way to achieve high-level objectives" [2].

The publication ([3], 2007) set out problems and goals of the FIRE (European project "Future Internet Research and Experimentation" as a part of ICT program FP7). The FIRE focused on exploring new and radically better technological solutions for the future Internet, while preserving the "good" aspects of the current Internet. The Internet increased by 7 orders of magnitude, and to cope with such growth, the simple original Internet architecture accredited hundreds additional protocols and extensions. The limitations of protocols appeared in situations of unusual traffic (real-time video, high-mobility of nodes and networks). Networks based upon this significantly more complex architecture turn increasingly difficult to manage. This stimulated a major debate amongst experts as to whether the current architecture and protocols can continue to be patched, or whether it will collapse under the demands of future applications [3].

"Many networking researchers around the world have identified the emerging limitations of the current Internet architecture and agree that it is time for research to take a long-term view and to reconsider the basic architecture of the Internet, to see if any better architecture can be identified, even if it does not appear backward-compatible at a first glance... It has to be stressed here that incremental and "clean slate" approaches are not competing, but complementary. Where in the short or medium term only incremental solutions can be envisaged, in the long term we have also to consider the possibility of fundamentally changing the Internet architecture or some of the underlying paradigms" [3].

In the US-Japan Workshop on Future Networks sponsored by NSF ([4], 2009), a number of research challenges were identified, including network fundamentals, architecture and methodologies of future network design. It was concluded, that "future networks requires rethinking current network design principles, exploring new paradigms that go beyond current circuit- and packet-switching techniques, privacy, mobility, and ease of management and operation. Also disputed whether traditional concept of layering is fundamental to network design, and if so, what layering-based framework and approaches will enable cross-layer optimization. What impact will current and emerging technologies, such as cognitive wireless devices and programmable optical links, have on network architecture, protocols and services? How transit to new architectures, especially if they are "clean slate"? ([4], Network Architecture Design, p. 36).

In 2010, the NSF Future Internet Architecture project (FIA, [5]) declared that "it is no longer clear that emerging and future needs of our society can be met by the current trajectory of incremental changes to the current Internet". By L. Zhang et al, proposed Named Data Networking (NDN) concept moving the today's communication paradigm ("where" are locating addresses, servers and hosts) to "what" is the content that users and applications care about [5]. In ChoiceNet project (by T. Wolf et al), the core idea of new network architecture formulated to support multiple alternatives choice, in order to let users vote with their wallet to reward superior and innovative services [5].

In 2011, a survey on future Internet architecture researches published in [6], where noted that current Internet is facing unprecedented challenges, and emerging demands hard to be met by incremental changes through ad-hoc patches. Instead, new clean-slate architecture designs based on new design principles are expected to address these challenges. "IP’s narrow waist of the core architecture is hard to modify, and new functions have to be implemented through myopic and clumsy ad-hoc patches on top of the existing architecture [6].

Also threshold in [6], that new Internet architecture must provide adaptation facilities for legacy devices, and those early adopters should have economic incentives for change. Any architecture that requires investment without immediate payoff is bound to fail. Of course, the payoff will increase as the deployment of the new technology increases, economies of scale reduce the cost and eventually the old architecture deployed base will diminish and disappear. Another important question for discussion was "Interfaces among stakeholders". "Future Internet architectures are required to provide extensible and flexible explicit interfaces among multiple stakeholders (users, Internet service providers, application service providers, data owners, and governments) to allow interaction, and enforce policies and even laws" [6].

G. Sallai wrote in his book "Chapters of Future Internet Research" ([7], 2013): "Telecommunications and the Internet are forming an increasingly integrated system for processing, storing, accessing and distributing information and managing content. Recently the content space is expanding by cognitive and sensory contents, billions of devices are to be interconnected, media convergence is highlighted and an open Digital Ecosystem is being formed. At the same time the identification capacity of the current Internet is running out, Internet architectures are reconsidered for better managing mobility and quality requirements, security issues as well as for exploiting the opportunities derived from the technological development and the new data handling and cognitive concepts. The future of the Internet became an important research area" [7].

Among the others, the following limitations of the current Internet highlighted: limited identification capacity; essentially private wire-line network concept; lack of guaranteed and differentiable quality of services; energy efficiency; interconnection of objects, devices, sensors. Also noted that "classic Internet aimed at interconnection of persons and contents, the Future Internet is aiming at the interconnection of devices, too, resulting in a two-pillar concept: Internet of People (Media Internet) and Internet of Things [7].

In 2014 S. Bao and H. Wu in their paper "Future Internet trends research" [8], considered that "Current Internet cannot afford the diversifying services any more. The network architecture should be improved or a clean slate architecture design is desired. Novel designs of future Internet become a hot topic. IPv6 is the improvement version of IPv4, which solves the address issue of the current Internet, but issues of routing scalability, security, mobility and Quality of Service are still remain. There are two ways to future Internet, improving ones and clean slate designs" [8].

In 2016 a survey on future Internet security made in [9] by W. Ding et al. The authors claimed, that "Current host-centric IP-networks face unprecedented challenges, and many research projects initiated the future

Internet design from a clean slate. Though, authors aim to move away from the traditional host-centric networks and replace them with content-centric, mobility-centric, or service-centric networks with respect to security issues [9].

A solid analysis of future Internet promising design was given by Hongke Zhang et al in the book [10] published in 2016. Mr. H. Zhang is currently a professor at the School of Electronic and Information Engineering (University BJTU, China) and director of a National Engineering Lab on Next Generation Internet in China. He proposed and prototyped a novel future Internet architecture called the "Smart Collaborative network". The book exhibits the future Internet concept called "Smart Collaborative Identifier NETwork: A Promising Design for Future Internet" (SINET). By examining cutting-edge research from around the world, the authors of [10] pose it to be the first book providing a comprehensive survey of SINET, including its basic theories and principles, a broad range of architectures, protocols, standards, and future research directions. Some SINET key technologies presented (scalable routing, efficient mapping systems, mobility management and security issues) [10].

In 2017 the book "Building the Future Internet through FIRE" [11] was published by V. Serrano et al. The project "Framework for Large-scale Federation of Testbeds" (Fed4FIRE) introduced. Since 2017 until 2021, the Fed4FIRE-successor project Fed4FIRE+ started. Also the MONROE platform presented, where registered users can select and access an available testbed. There also presented "Federation of Heterogeneous Cloud and Networking Testbeds" (BonFIRE) for applications, services and systems, based on federating geographically distributed heterogeneous cloud testbeds; among them, five testbeds offered: "OpenNebula", "HPCells", "Virtual Wall", "VMWare vCloud", "Amazon EC2" [11].

The perspectives of the space communication and space Internet reflected in [12]. The challenges focused there, ranging from acquiring regulatory approval to technical and practical limitations (potential damage to property, orbital debris etc). Consensus was found, that worldwide Internet availability would ultimately be beneficial, given both humanitarian and economic concerns for poor and wealthy nations. Herewith, the Internet Service Providers (ISPs) should be addressed as potential distribution partners for novel systems. Significant challenges of the future of IoT will be diversity of devices [12].

As noted in [13], presently centralized server/client architecture utilized to authenticate and connect several terminals in a network is solely appropriate for the current situation and is not scalable to cater future needs with billions of devices. This will transform the current system into a bottleneck. Large amount of investments and expenditure in maintaining the cloud clusters of servers are required which can deal with humongous quantity of information exchange, as unavailability of servers can lead to a total system shutdown [13].

An exhaustive analytical review of related projects and challenges of the Future Internet is presented in the book "Flexible Network Architectures Security: Principles and Issues" (B. Rudra, [14], 2018). In this book, there are indicated such principles as "Simplicity of Internet architecture", "Intelligent end systems", and "Collaborating networks", consider Internet as collection of networks. Many researches observed that end-to-end (E2E) arguments served as a basis of architectural paradigm in Internet debate for 20 years. Although it was believed by leading Internet researchers that the end-to-end arguments cannot support the application level function and preferably should not be built into the lower levels of the system [14].

Some researchers have identified and broadly classified the Internet design goals into main and secondary goals. Rudra thresholds in [14], that "TCP/IP assumes a fairly simple and predictable notion of the E2E delay and packet loss, but this does not always hold well in a dynamically varying mobile environment. The TCP/IP was designed for wired networks, but not for wireless network, so handling data link layer in wireless media requires a different approach" [14].

Consider the ATM technology, Rudra wrote: "There was hype in the Internet community that the ATM would be the foundation for future telecommunication network. However, providing a guaranteed QoS on ATM was very complex than that of the Internet. And the average packet size of ATM cell is 1/10-th of that on the Internet. As a result, the speed of the ATM dropped down by 10 times. Point-to-multipoint communication using ATM are realistic and are observed in a pure ATM network ... But the coexistence of ATM network at a data link layer on the top of Internet is not realistic which is being equivalent to IP multicasting, and resulted in more expectations from multicast. This resulted in unwanted IGMP traffic generation which delayed the response time. The current Internet does not support direct implementation of ATM technology on the existing infrastructure, which requires heavy infrastructure investments. Due to some of these limitations it is hardly hardly used anymore as one of the Internet technologies" [14].

Also, the limitations of IPv4 and IPv6 observed in [14]. "As IPv6 inherited ... some of the problems of IPv4 ... there is an alarm for collapse of the Internet … Some of the limitations of the IPv4 are overcome as improvements in IPv6 such as Neighbor Discovery (ND) ... IPv6 can link a variety of lower layers due to its simplicity and hence it became a standard protocol for linking lower layers. Currently ATM, PPP and Ethernet are considered as some of the lower layers on which the implementation of IP is very well supported. Although neighbor discovery was designed as a universal protocol over lower layers, the problem of adopting to new lower layer requirement is uncertain and a new kind of limitation is expected in due time. As the link broadcast is not supported by IPv6 so for the neighbor discovery it uses multicast functionality. This made IPv6 completely depend on the functionality of IGMP ..., due to this, all the limitations of IGMP protocol got directly inherited to IPv6. IPv6 uses timeout specifications of neighbor discovery as well as IGMP ... Many new technologies such as ATM, Frame Relay ... emerged for the improvement of current network systems but could not succeed to get evolved and qualify as possible alternatives" [14].

Addressing the possible scenario of migration towards the Future Internet, Rudra said in [14]: "Most of the approaches adopted patch-work approach to cope with the need and aspirations of the network community in which it is desirable to have evolution and revolution of technology growth with acceptable cost and speed along with flexibility as a prerequisite for a continuously changing scenario ...".

At the same time patch opened a way for creation of some new problems. This is not due to the inherent problems of protocols rather it is an issue of the architecture of the protocol ... The view is broad, covering many technologies, and many issues but not very detailed. The functionalities of today's Internet have been divided into several layers considering their abstraction level, but the experts in the networking community could not agree on a specific number of layers. As a result of this, the TCP/IP model has 5 layers and OSI has 7 layers, etc.

Moreover, the placement of functionality in the layered approach is sometimes difficult to decide. In addition, the dependency among the protocols and functionalities is hard-coded making the architecture inflexible. However, this is remarkable in that the history considered here covers many services and its issues, including security limitations". Also noted, that Internet foundation identified several pillars of the future Internet ("Internet by and for the people; Internet of Things; Internet of contents and knowledge"), as well as new challenges associated with these pillars [14].

In 2019, the paper "Future Internet: trends and challenges" was published by Jiao Zhang at al. [15]. In that work some cases presented for architectures and technologies to meet challenges caused by diversity of applications (cloud computing, Internet of Things, and the industrial Internet), as well as integrated framework proposed to combine the strength of current architectures. Some open challenges and opportunities for future Internet discussed.

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Two main reasons for limited network development highlighted in [15]. "On the one hand, there has been no break-through in the contemporary Internet architectures since the 1970s, and the scalability and flexibility of networks are limited by the "thin waist" Internet Protocol (IP) model, which is an end-to-end channel between two endpoints identified by IP addresses ... On the other hand, because the traditional equipment is not programmable and hard to upgrade, existing network infrastructures are struggling to support new network innovations, which makes it difficult to test new network architectures and develop new network protocols ... Future Internet can be explained as new architectural designs with fundamental innovations for a next generation Internet ... Latency and bandwidth are the most important performance metrics for networks ... Online … type of service is very sensitive to network latency ..., big-data ... and online storage ... are very sensitive to network bandwidth ... In addition, as the number of users and the amount of data traffic increase, the wide area network and mobile network face challenges in latency and bandwidth" [15].

Particular importance of the packet latency curb also focused in [15]. "Specifically, the 5G network is expected to support data rates up to 10 Gb/s and latency at around 1 ms ... Thus, how to decrease latency and increase bandwidth becomes the basic requirements for the future Internet ... The architecture of the traditional network is not flexible enough and cannot support significant modifications ...".

The design goal for IP is to support end-to-end communications. This means that new features and protocols can be deployed only in a "patched" fashion ... Furthermore, because the network nodes like switches and routers are not programmable, there is almost no practical way to experiment with new network protocols ... Hence, as more and more new protocols are developed, network nodes become very complex with a very low scalability. Therefore, to support a flexible data plane, the future Internet requires innovation in the network architecture and programmable network devices". Some promising technologies are considered while migration to Future Internet, such as Network Functions Virtualization (NFV), P4 programming language, Edge computing [15].

New services such as Industry 4.0, smart city, autonomous driving, and the Internet of Vehicles require not only a high bandwidth but also a low latency. They usually require deterministic or bounded latency. Recently, some time-sensitive networking (TSN) and deterministic networking (DetNet) developed to provide end-to-end latency guarantees across the Internet [15].

"However, TSN can work only in LAN and cannot be used in WAN, whereas the standard and technology of DetNet are working in progress ...

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Control the latency and jitter is still a big challenge. Considering the existing technologies, we think software-defined WAN (SD-WAN) is a promising way to solve the problem. For instance, in SD-WAN, the controller can control all flow paths. Thus, we can use multiple paths and split the WAN paths into two types: low priority and high priority. The latency of high-priority paths is guaranteed by limiting the total traffic on the path, while the latency of low-priority paths is not guaranteed without limiting the total traffic. Furthermore, to control the traffic, we should limit the rate of a flow in the source node instead of in the network. Currently, the management and orchestration of the network bring challenges and opportunities in two aspects. On the one hand, real-time network status data are required as basic elements. Hence, network-wide telemetry technologies are essential. Some recent work ... adopts P4 to perform in-band network telemetry" [15].

4. Discussion on Future Internet issues. This section summarizes publications discussed above. Major disputed questions group in three categories: the Internet complexity as an object of study; unsystematic evolving the Internet; the Internet bottlenecks.

<u>Complexity of the Internet</u> as an object of study.

The far from complete survey of publications shows that the modern Internet is a very complex object for research, analysis and forecasting. This complexity caused by a great number of network entities that interact on various levels: technical devices, research centers, universities, groups and projects, international regulatory institutions (ISO, ITU, IEEE, IETF) and many others. In general, complexity of an object depends not only on the inner essence, but on its outer shape with respect to particular individuals. We assume that any complex (at first glance) object or system can be shaped in a rather simple and transparent view for a target audience. In other words, an object's complexity fairly depends on its model for a target audience. Thus, we may conclude, that creation a common model of a large object like Internet, which would be equally transparent for different target audiences, seems an ungrateful task.

<u>Unsystematic evolving the Internet</u>.

Apparently, Internet previously developed by "patches", primely reflexing raised issues. This caused a conglomerate of protocols which not initially foreseen by OSI model or TCP/IP stack. This led to unjustified equipment and channel overloads. Some experts claim the need of radical reconfiguration the future Internet. The question is, whether it really necessary to fundamentally rebuild the future Internet, or better to incrementally evolve the current Internet avoiding radical transformations.

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The Internet bottlenecks. Many experts emphasize that legacy multi-layered architecture of the Internet is alike to hourglass, i.e. has a wide base and top, but narrow waist. And this “narrow waist” of current Internet is IP, which not changed much since Internet founding in the 70s. At the same time, technologies of the physical and data link layer, as well as network applications, have stepped far forward. Towards IP, the following three concerns can be distinguished.

Identification and routing. The rapid increase in the number of objects interacting via the Internet, is a challenge for their identification and localization in the Net. Now two IP addressing systems coexist: IPv4 and IPv6. The IPv4 public addresses mostly exhausted. They also can bind with domain names supported by DNS. The IPv6 has extended 16-octet addressing, but in visible perspective, such addressing leads to data overhead and resources under-usage. The "narrow waist" of the legacy Internet model is particular tangible in IPv4 cross-domain routing being rather complex computational task.

Cross-domain streaming. The over IPv4 packet delivery of small messages is not a problem, if no E2E "big data" transfer, or real-time interaction required. In IPv6, a special 20-bit flow label is provided for streaming data. However, the over IPv6 flows switching is challenging while inter-domain data streaming.

End-to-end packet delay. The volatile latency of IP-packet is critical issue for E2E voice delivery, M2M- and sensor-systems, on-line conferences, etc. This problem is mitigated on data link layer within separate AS. An example is VoLTE network deployment by Verizon Co which ensured the standard one-way-delay for voice-packet transmission across the USA. However, this only became possible after Verizon Communication (a world-wide Internet provider) outbid its shares of Verizon Wireless in USA in 2013 from Vodafone Group for $ 130 billion. This was the price at which Verizon combined own backbone networks with mobile access around the USA into a common autonomous system. Thanks to this, the company managed to avoid cross-domain IP interactions for telephone traffic. The year after, voice over LTE was launched [16].

5. Internet as a complex system. The experts vision of today Internet is impending collapse of its legacy architecture built about 50 years ago on the basis of TCP/IP model. Also an urgent need emerged in developing truly new framework of the future Internet, regardless technological and other constraints. This question is rather controversial - what is better: evolution or revolution in progressing the Internet? As clear from publications considered above, an idea dominates there that, despite visible obstacles, fundamental researches are to be continued about the future Internet architecture. Moreover,

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deep studies on the topic must diverse and compete across the countries and regions, as well as go on large-scale test-beds. Also was noted that evolutionary and revolutionary ways of Internet progressing should not be opposed, but rather complement each other.

Sharing these ideas on the whole, we'd add one thesis more. Maybe it's worth get ready to meet a "revolutionary scenario", still trying to avoid upheavals through timely balanced changes at most critical pillars of the system? The inevitability of a "revolution from scratch" may arise beyond our will due to force majeure events, as well as due to our insufficient attention to those signals sound from the "weak links". Here is about ad-hoc cases (crises, cataclysms, disasters etc) which can dramatically speed up translation of bold ideas in practice, yet perhaps at a high price. Apparently, one would hardly voluntarily pay a high price for "tabula rasa" redesign of his "large home". Based on the foregoing discussion about the "future Internet" architecture and its vision by the experts, we formulate further on three cognitive principles of our approach to design the future Internet: *necessary simplicity*, *nested hierarchy*, *ternary clustering*.

Necessary simplicity. The more fundamental and promising a design solution is, the more transparent it should be for interested specialists, officials, managers and administration. This means that, an overall big project view should abstract from its specific details and focus the essence. Otherwise the project perception and approval are challenging.

Understanding impediments in ARPANET project launch (as predecessor of the current Internet), which originated from theoretical publications, next got funding support in experimental researches, until the first tangible results obtained (these facts can be supplemented by many others), one may grasp and accept the following statement.

Breakthrough decisions often stumble upon rejection among professionals and even society as a whole, due to the conservative public consciousness. This is neither bad nor good, but worth accepted when going on to put bold ideas in life.

Nested hierarchy. This principle complements and refines the concept of necessary simplicity, when apply to nested parts of a large system. In other words, we'll shape the Internet model as a multi-level hierarchy, any level of which embraces simple partial models of the whole one. On the one hand, the Internet as an object of study may look rather complex system if simultaneously observing at many or even all levels. Such a view may be needed by few professionals responsible for developing the Internet. But, for specific target audience (students, functionaries etc.) individual simple models of the complex Internet architecture can be constructed.

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Ternary clustering. This principle supplements the first two, namely, it determines optimal (in a certain sense) variety of entities that makes up each part of the system at any hierarchy level. There might be subjective and objective criteria taken for optimal diversity in a system model. The fact is, few people can logically put together and analyze an enormous number of entities at once. In turn, some individuals would hardly able to handle even few ones. For instance, some students easily understand the ten-element flowchart, while many others prefer minimize the number of entities to acceptable rate. However, also objective regularities exist in the matter of "things ordering". The insight about how the distinct entities around can be better ordered roots back in deep past. Some ancient peoples believed that the Earth rests on three whales as a "triad basis" of the Universe. The ancient philosopher Hermes in his doctrine "Trismegism" claimed that he had been “three times great” because he knew three great "truths". It's no matter what those "truths" mean today, as ancient notions inadequate to our perception today. More important that exactly "three" things declared (here an error in ancient text translation is practically excluded). The number "three" also plays a fundamental role in Christianity (the “holy trinity” doctrine - Father, Son and Holy Spirit).

On the other hand, in our recent history, the strict math solution was obtained for the most compact numbering a given set of things. In the last century, great mathematician, J. Neumann investigated what bases of number systems are most informative. In fact, multi-digit numbering is a relevant form of hierarchical ordering for multitude parts of a whole one. We used to decimal numbers. Most digital schemes are built on binary numbers (or its mixed derivatives). But J. Neumann proved that most informative basis of system numbering is the transcendental number "e", approximately equal to 2.7. Today, the number systems with the exact base "e" are unknown, but the closest integer base is 3.

Ultimately, the cognitive aspects of logical categories identification and numeration are not only actual in system researches, but also in other cases, as academic study, business activity [17].

The known "Turing machin"” (which is a kind of standard for describing digital programmable automata's) has an alphabet of *three symbols*: two letters ("0", "1") dedicated for "command words", and one syntax symbol "space" for separation the words in a continuous sequence of commands [18]. Also, "*ternary logic*" is used with two definite states complemented by a third "indefinite" one [19]. In the 60s, Odessa philosopher A.I. Uemov introduced *ternary logical analysis* defined on the so-called "*Systemic triad*" <things, properties, relations> [20]. The authors experience of teaching students also

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proves the relevance of ternary clustering different things, notions, and elements in academic disciplines.

Based on addressed ideas and facts, we assume the "*ternary clustering*" as an optimal categories ordering in a multi-level system architecture.

6. Future Internet vision. Using aforesaid principles of large system analysis (necessary simplicity, nested hierarchy, and ternary clustering), we introduce an overall framework of future Internet shaped in three nested realms: Internet Core, Edge, and Shell, fig. 1. Three main entities are highlighted within the Shell (people, things, and robots). The Edge contains three clusters: mobile devices, stationary servers and sensor network controllers. The Internet Core includes three categories of packet-based transport considered further on.

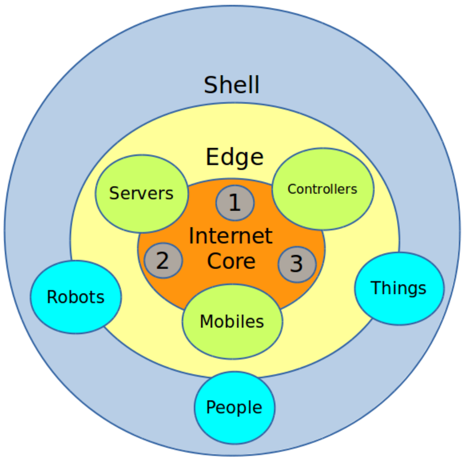

Fig.1. Nested ternary framework of the Future Internet

All the multifaceted aspects of the future Internet are certainly important and require the attention of developers. However, the model in fig.1 sets priorities - first of all, building a solid core of the future Internet through the evolution of the existing Net. Inside the Internet Core, there formed three main categories in accordance with the previously discussed "hourglass-model" of the current network architecture:

a) "all below IP" (competence of AS administrator);

b) "IP narrow waist" (shared competence of large telecoms players);

c) "all above IP" (competence of standardization institutions, equipment manufacturers, and application developers).

Today, IP is a "narrow waist" of the Net, tight with noted issues (identification-routing; cross-domain streaming; end-to-end latency). An objective reason for that is poor interoperability between adjacent AS within the network Core. For this reason, ISPs tend enlargement, while their quantity decrease. Another hitch leis in "Edge-to-Core" interface (fig.1) when over IP data processing in real-time mode. These factors hinder the QoS in big data transmission, and on-line applications. However, replacing IP is a tough, both in technical and organizational aspects, as huge amount of IP based apps deployed around the world will be at risk.

An acceptable solution to IP bound problems at the "Edge-to-Core" interface (fig.1) may be to complement IPv4 by two protocols more (one for big data streaming, another for real-time data transfer with latency control). However, the most challenging is AS-to-AS interface in the Net core, which not only relies on IP, but also held by lower data link layer, since IP packets not directly transmitted between neighbor domains; instead, carried by L2 protocol data units (e.g. Ethernet frames).

In this paper, the following way out offered of this situation as a primely step. It is to create a NewIP-over-L2 protocol for cross-domain interaction instead of IP-over-L2, which could be introduced gradually in distinct segments of the Internet core. The NewIP-over-L2 protocol can be mutually implemented to join pairs of adjacent autonomous systems. That will be step-by-step ongoing process for QoS improvement across the routes that pass given joint. Of course, such a solution looks more complicated than inner upgrade within a separate autonomous system. Yet, such a solution is simpler than simultaneous protocol upgrade across entire Internet core. Besides, one can act step-by-step even deeper within cooped domains, involved in upgrade experiment. For this purpose, given physical AS-AS link make split in two sub-channels - the first one remains for legacy usage, while another be reserved for NewIP-over-L2 protocol experiment. The outlined way of migration to Future Internet may be a good chance for cutting-edge players in telecoms.

To collaborate in Future Internet efforts, the coauthors here advert that over the past 10 years, Odessa National Academy of Telecommunication (ONAT) conducts theoretical and experimental researches on “Future Internet”. Novel protocols of packet data transfer have been designed. Numerous publications issued, and practical results achieved. Were defended one doctoral-, two PhD- and twelve master-theses on future Internet architecture, technologies and data transmission methods, [21 – 24]. In particular, the following protocols are presented in PhD theses [24].

1) LCP (Logical Connection Protocol) for big data fast streaming between the Internet Core and Edge entities (fig. 1).

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2) VCP (Virtual Connection Protocol) for multi-channel transmission of real-time data (audio, video, telemetry) between the Internet Core and Edge entities (fig. 1);

3) CMP (Conveyor-Modular Protocol) for multimedia data transfer within the Internet core between any two adjacent autonomous systems or domains. The CMP provides multiplexing of three types of multimedia data: conventional IP packets, big data streams, real-time data. The multimedia data are carried via Raw Socket Ethernet frames periodically circulating in the channel.

Conclusion. The Internet development issues are widely discussed, as legacy TCP/IP Internet architecture no longer meets new challenges. Redesign of the Internet is a tough problem, primely because of its huge scale. In this work, an attempt made to cognitive approach the Internet as a large hierarchical system. The background of Internet and its state-of-art have been addressed for better insight its possible perspectives. Related publications briefly surveyed around the past 15 years. Some critical "pain points" of the current network infrastructure identified. Original systemic ideas substantiated and relevant constructive solution proposed for step-by-step migration towards the Future Internet due near and medium term. The coauthors open for creative cooperation on "Future Internet" researches with interested companies, specialists and institutes.

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Інтернет майбутнього – проблеми і перспективи / Тіхонов В.І., Тихонова О.В., Цира О.В., Яворська О.М. // Вісник НТУ "ХПІ". Серія: Інформатика та моделювання. – Харків: НТУ "ХПІ". – 2020. – № 1 (3). – С. 123 – 141.

Розглянуті питання сучасної архітектури Інтернету. Наведено короткий огляд актуальних публікацій. Обговорено перспективи міграції до Інтернету майбутнього. Сформульовані когнітивні принципи для вивчення Інтернету як складної системи. Окреслене авторське бачення Інтернету майбутнього. Запропоновані основні кроки для реорганізації рівня IP в моделі TCP/IP при переході до майбутньої архітектури Інтернету. Іл.: 1. Бібліогр.: 24 назв.

Ключові слова: архітектура майбутнього Інтернету; системний підхід; TCP/IP.

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Рассмотрены вопросы современной интернет-архитектуры. Дан краткий обзор соответствующих публикаций. Обсуждаются перспективы миграции в Интернет будущего. Сформулированы когнитивные принципы для изучения Интернета как сложной системы. Изложено авторское видение будущего Интернета. Предложены основные шаги, предлагаемые для реорганизации уровня IP в модели TCP/IP при переходе к будущей архитектуре Интернета. Ил.: 1. Библиогр.: 24 назв.

Ключевые слова: архитектура будущего Интернета; системный подход; TCP/IP.

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The issues of the current Internet architecture considered. A brief survey of related publications given. The perspectives of migration to the Future Internet discussed. Cognitive principles formulated for study Internet as a complex system. An author's vision of the Future Internet outlined. Primary steps proposed to reorganize the IP layer in TCP/IP model when transition to the Future Internet architecture. Figs.: 1. Refs.: 24 titles.

Keywords: future Internet architecture; system approach; TCP/IP.