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Circuit Switching is Coming Back?

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Abstract—Communication specialists around the world are facing the same problem: shifting from circuit switching (CS) to packet switching (CS). Communication service providers are favoring "All-over-IP" technologies hoping to boost their profits by providing multimedia services. The main stakeholder in this field of the paradigm shift is the industry itself: packet switching hardware manufacturers are going to earn billions of dollars and thus pay engineers and journalists many millions for the promotion of the new paradigm. However, this drive for profit is tempered by life itself. This article is devoted to the discussion of the telecommunications development strategy. We will provide examples to illustrate the difficulties that complicate the transition from CS to PS and make us question the feasibility of shifting the telecommunications paradigm. We will consider two examples:
(1) the development of the global information grid (GIG) of the United States Department of Defense communications network, the world's largest departmental network, which is still based on SS7 signaling and an intelligent network;
(2) the emergence of new trends in microelectronics: the construction of networks on a chip (NoC) oriented towards packet switching, where a return to packet switching is observed.

Keywords: circuit switching, Clos switch, packet switching, network on a chip
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1. INTRODUCTION: TELEPHONE BACKGROUND

The older generation of communications specialists remembers electromechanical switches built upon crossbar switches or reed matrices. The voice transmission channel in such switches was formed from fragments of a cumbersome switching field (Fig. 1), and switch equipment occupied entire floors of buildings.[1]

With the transition from analog to digital voice transmission (8000 counts of one byte per second), the volume of equipment was sharply reduced. The inputs of the electronic switching field receive a stream of numbers at 2048 Kb/s, which houses 32 flows of 64 Kb/s each. This mode is called time division multiplexing (TDM), and the nature of the switching is moving bytes from one time slot to another. The supreme achievement of the circuit switching era was the introduction of the SS7 signaling system (a sort of packet network between telephone exchanges), which accelerated the process of connection setup and, most importantly, served as the basis for constructing intelligent communication networks.

Digital switches still dominate in communication networks, maintaining tough competition with packet switching equipment. The most well-known are the AXE type switches manufactured by the Ericsson company of Sweden and developed in the 1970s. They implement the heritage of crossbar exchanges of the ARF, ARM, ARK, and ARE types (developed in the 1950s), which are still in use in some places. The second place belongs to the Alcatel-Lucent group company of France, the Netherlands, and the United States. It is associated with the following switches: Alcatel E10 (development of Alcatel), 1000-S12 (created after the IT&T acquisition), and Western Electric 5ESS (after merging with Lucent; it can be traced back to Bell Laboratories works). In recent years, the telecommunications market is experiencing the expansion of the Huawei company (China).

We are interested in the mathematical methods of researching the switch field capacity and the possibility of transferring this knowledge to NoC. Of the many names we will only mention Charles Clos [2] and Vaclav Benes [3] at Bell Laboratories, where these studies were conducted intensively even before the 1950s. The scheme in Fig. 2 directly belongs to switch matrices on crystals. This is a rearreangable non-

[1] Example source: operation of the VEF plant in Riga, Latvia. The switching field of a long-distance switch "Quartz" with 8000 conversational channels occupied the area of a basketball hall.

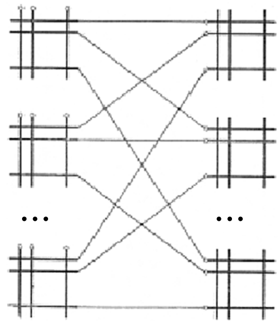


Fig. 1. Two-stage crossbar switch example.

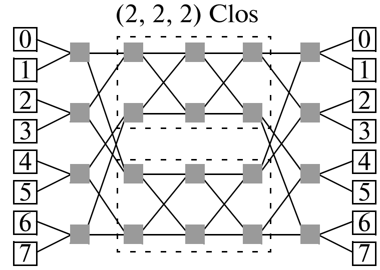


Fig. 2. Benes–Clos circuit diagram.

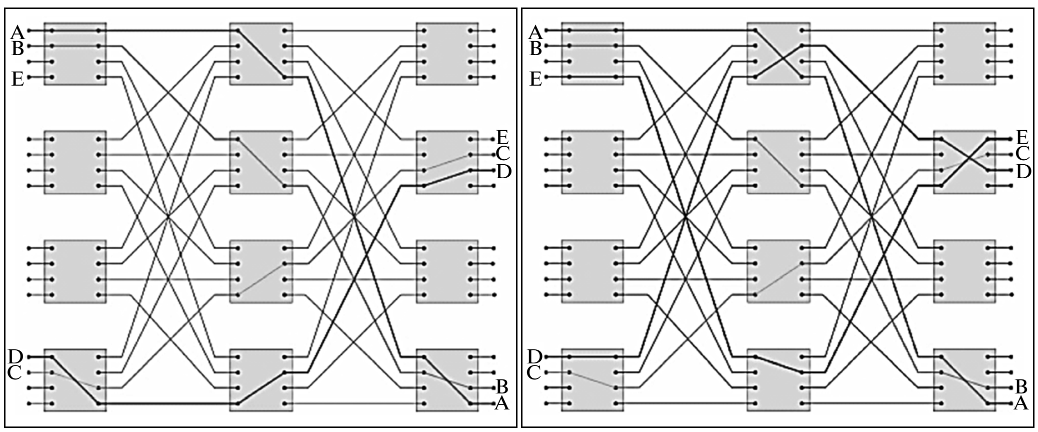


Fig. 3. Reswitching example: in the diagram on the left, A, B, C, and D connections are established; E is blocked. In the diagram on the right, after connection D rearreanging, it is possible to establish additional connection E.

blocking Benes 8 × 8 scheme, which includes two Clos 2 × 2 × 2 schemes. Figure 3 illustrates an example of rebuilding the paths in a switch field that eliminates connection lock.

2. HOW IS THE GLOBAL INFORMATION GRID BEING DEVELOPED

2.1. Joint Vision 2010 strategic plan: orientation towards AIN. The Defense Information Systems Network (DISN) belonging to the Pentagon is the world's largest departmental network [1]. The DISN has been developed since the early 1990s. This is a global network. It is intended to provide communication services by transmitting different types of information (voice, data, video, multimedia) in order to perform the efficient and secure control of military, communications, intelligence, and electronic warfare media. In 1996, the state of the DISN was panned. First of all, due to the low level of integration of members of the DISN networks, which significantly limits the interaction capabilities within a single network and prevents the effective unified management of all its resources. In particular, there was noted the complexity of the interaction of stationary and field (mobile) components of the core network due to different standards being used, the types of communication channels (analog and digital), the services, and the capacity (the bandwidth of mobile components is significantly lower than that of stationary ones).

In the development of the next phase of the DISN network, the DISA agency has taken an unprecedented step for the Defense Ministry: it required the usage of only the finished commercial products in the field of new information and network technologies. The emphasis was placed on open systems, which are based on national standards, and the latest commercial technologies and services available on the market (commercial-off-the-shelf, COTS).

These requirements are reflected in the 15-year program of weapons development entitled Joint Vision 2010, which the United States Department of Defense Command (United States Joint Chiefs of Staff) adopted in October 1996. Regarding the means of communication, the Advanced Intelligent Network

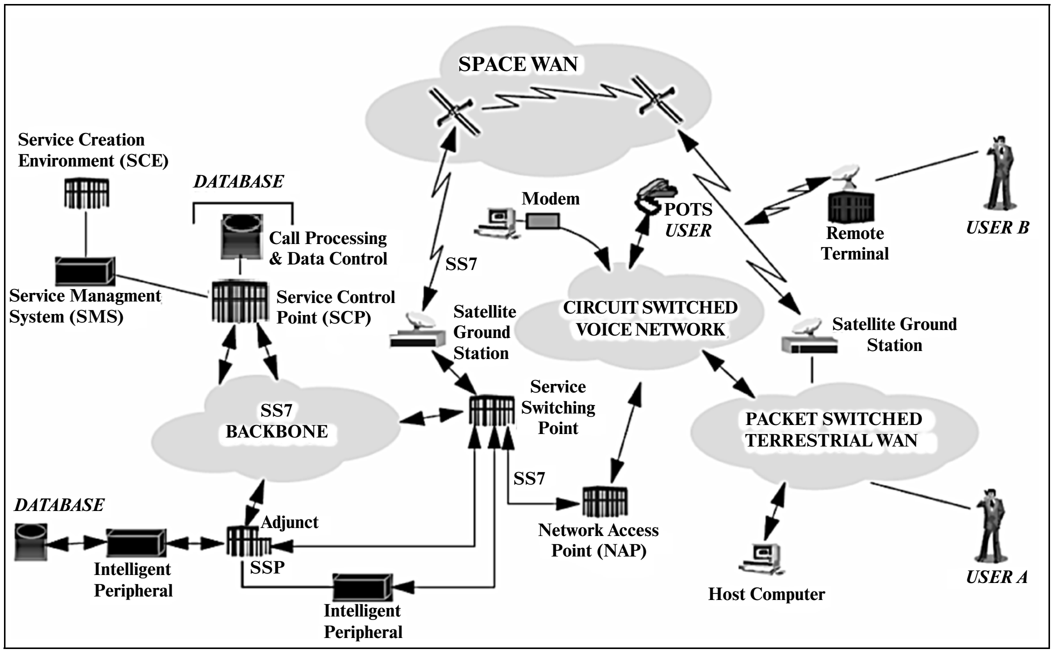


Fig. 4. Advanced Intelligent Network (AIN) architecture.

(AIN), the highest achievement in the art of circuit switching, was chosen. This fundamental decision was reported by the DISA representative in 1999 at the International Conference on Military Communications MILCOM'99 [4]. Here is a quote from his speech:

"The future DISA networks will enjoy the benefits of IN software. AIN services will form the core of the development technology, assessment, and DoD data transmission technology. The results of the AIN services will provide the military commanders the ability to collect, process, and transmit information without interruptions in the network service. The AIN capabilities will become the cornerstone of the DoD information superiority."

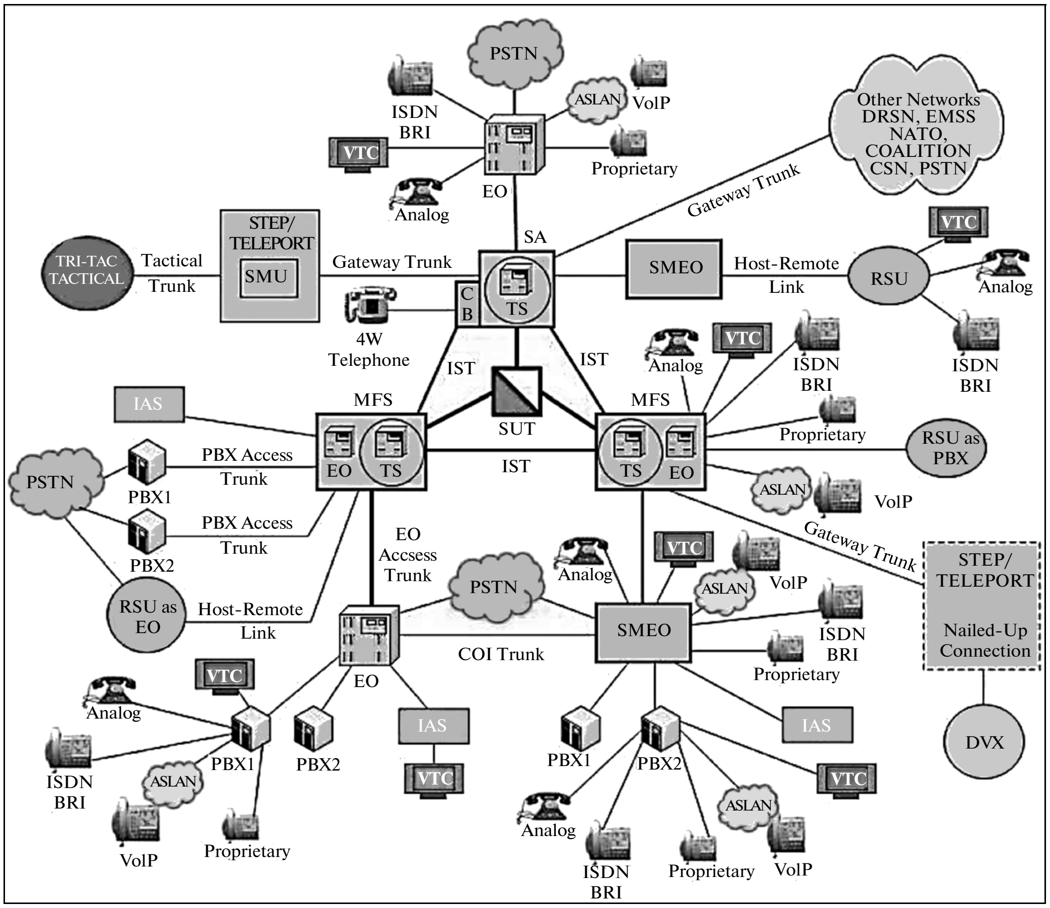
Signaling system SS7 is the interlink of the AIN network (Fig. 4): SS7 provides access to databases (DATABASE). Channel switching network subscribers, as well as packet switching network subscribers, can be AIN users. Intelligent Peripheral also plays an important role: its functions include tone generation, voice recognition, speech and data compression, dialing recognition, and much more, including tactical and strategic services for personnel identification.

The SS7 network is, figuratively speaking, the nervous system of a DSN switched network. Figure 5 and 6 originate from the documentation on testing the SS7 network as the part of the DSN network conducted by Tekelec in 2011 [5]. The center of the diagram is occupied by the system under test (SUT) block, which is the SS7 network undergoing the test. That is, within the DSN defense network, the connections are established by means of SS7 signaling and, in the periphery, devices of any type are used. The devices are connected by any protocols: 4-wire (4W); classified LAN, ISDN, and BRI (ASLAN); Internet telephony (VoIP); video conferencing (VTC); any nonstandard protocol (proprietary); a link via communication satellites to remote DVX telephone networks and tactical networks at theaters of military operations (STEP/TELEPORT).

Figure 6 shows the manufacturers of telephone equipment used within the DSN defense network: at the level of SCP controllers, there are switches manufactured by Alcatel-Lucent and Siemens. Note that, on the right side of Fig. 6, there are two local area networks (Local LAN) that, via a switched network, transfer information encrypted by the Secure Shell Tunneling (SSH) protocol.

Hence, there is an important conclusion: the DSN network tends to adopt new terminal equipment (to a large extent, this is IP equipment), and the SS7 network retains its central position. The presence of the SS7 network is not an obstacle to the transition to IP protocol.

2.2. Joint Vision 2020: orientation towards IP protocol. In 2006, the Pentagon adopted a new plan for the next 15 years entiltled Joint Vision 2020. The plan announced a DISN paradigm shift: the transition from SS7 signaling to IP protocol [6]. It is assumed that the IP protocol will be the only means of com-



LEGEND:
4W 4-Wire
ASLAN Assured Services Local Area Network
BRI Basic Rate Interface
CB ChannelBanic
COl Community of Interest
CSN Canadian Switch Network
DRSN Defense Red Switch Network
DSN Defense Switched Network
DVX Deployable Voice Exchange
EMSS Enhanced Mobile Satellite System
EO End Office
lAS Integrated Access Switch
ISDN Integrated Services Digital Network
IST Interswitch Trunk
MFS Multifunction Switch
NATO North Atlantic Treaty Organization
PBX Private Branch Exchange
PBX 1 Private Branch Exchange 1
PBX 2 Private Branch Exchange 2
PSTN Public Switched Telephone Network
RSU Remote Switching Unit
SA Standalone
SMEO Small End Office
SMU Switched Multiplex Unit
STEP Standardized Tactical Entry Point
SUT System Under Test
Tri-Tac Tri-Service Tactical Communications Program
TS Tandem Switch
VoIP Voice over Internet Protocol
VTC Video Teleconferencing

Fig. 5. Defense Switched Network (DSN) architecture.

munication between the transport layer and applications (Fig. 7). However, the timing of this transition was not announced in the plan.

Figure 8 illustrates the main problem that the GIG network developers are facing: they should shift from CS to PS, but how? As for today, GIG is based on circuit switching (more specifically, on the SONET standard for the optic cables functioning), and the information is coded according to the time division multiplexing (TDM) telephone standard. This circuit switching network is currently used by the major military communication networks of the Pentagon:

(1) the Defense Switched Network (DSN) telephone network;

(2) the Defense Red Switched Network (DRSN) secure switched network;

(2) the DISN VIDEO (DVS) video conferencing network.

Figure 8 also shows four classified networks: JWICS and AFSCN (work in the ATM network); NIPRNet and SIPRNet (work in the IP network).

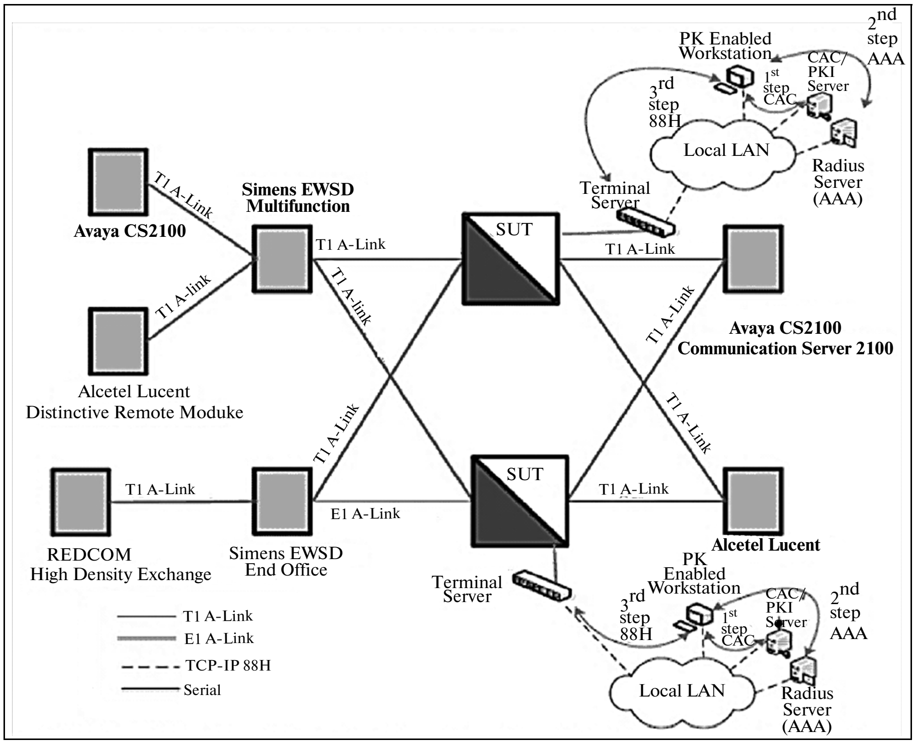


Fig. 6. SS7 network under a test configuration.

2.3. From GIG1 to GIG2. In 2006, the management of the Command, Control, Communications, and Computer Systems (C4 Systems) department in the Pentagon panned the GIG network status and announced the transition to a GIG2 network. The main disadvantages of the existing GIG network are as follows: there are many networks with different equipment, uncoordinated decisions to ensure secrecy, uncoordinated programs to conduct combat operations in different military branches, and differences in data bases. These drawbacks should be eliminated in the new version of the network: GIG2 [7]. Here is a remarkable quote from Michael Basla directed to the manufacturers of military equipment in 2009 [8]: "We don't need more boxes." He reminds them that currently the military uses 40 different communication systems: "We've got enough boxes. Help us make those boxes talk to each other."

In 2012, the DISA agency published a guidance document GCMP 2012 [9] with the new requirements for the GIG2 development methodology. The new architecture is based on the cloud computing model, and this makes it different from the previous models, which were network-centric. Unfortunately, this document doesn't contain anything regarding the fate of the previous architectural decisions: SS7 signal-

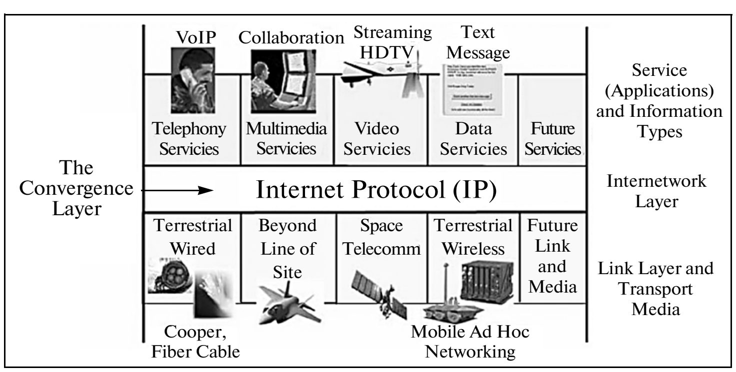


Fig. 7. IP protocol—a single protocol of a Global Information Grid (GIG) network.

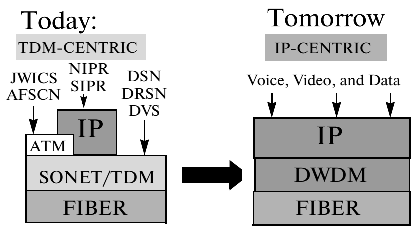


Fig. 8. Illustration of the current GIG problem: how to move from a TDM network to an IP network.

ing, AIN network, and IP protocol. The basis for the new concept is the model based systems engineering (MBSE) and systems modeling language (SysML). The MBSE model itself is a collection of charts in the SysML language, which is similar to the universal modeling language (UML).

A reasonable question arises: will there be sufficient human resources to rebuild the existing 40 communication systems of the Pentagon, which link several satellite constellations, air and naval forces, the Army, and much more; to write unified requirements for all the networks; to translate them into the SysML language; and to create the program code for the unified GIG2 network? It may well be that the GIG core—the SS7 signaling and AIN network—will stay there for an indefinite amount of time and thereby the generation of equipment based on the principles of circuit switching will remain as well.

2.4. Network on a NoC crystal: CS versus PS. Consider the confrontation of CS and PS supporters in one particular but very important area—microelectronics. NoC schemes were initially developed for packet switching, while considering circuit switching as a side option. However, in the latest years, there are works denoting the opposite: in the NoC market, circuit switching (CS) products can take the field from packet switching (PS) products.

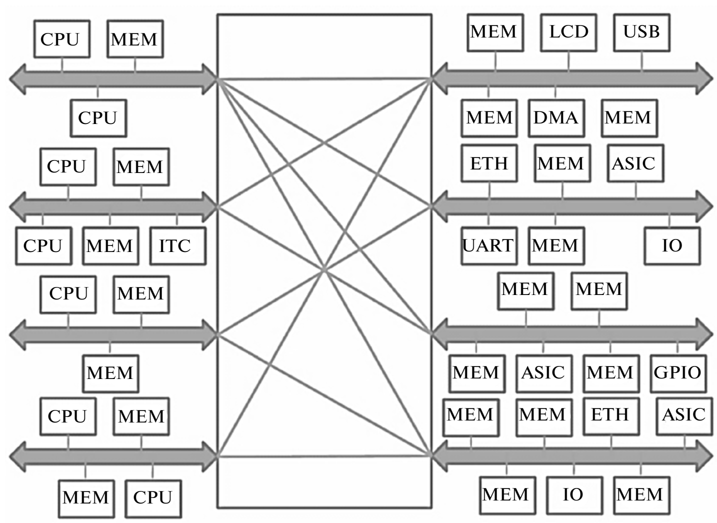


Fig. 9. Single-crystal microchip (NoC) example.

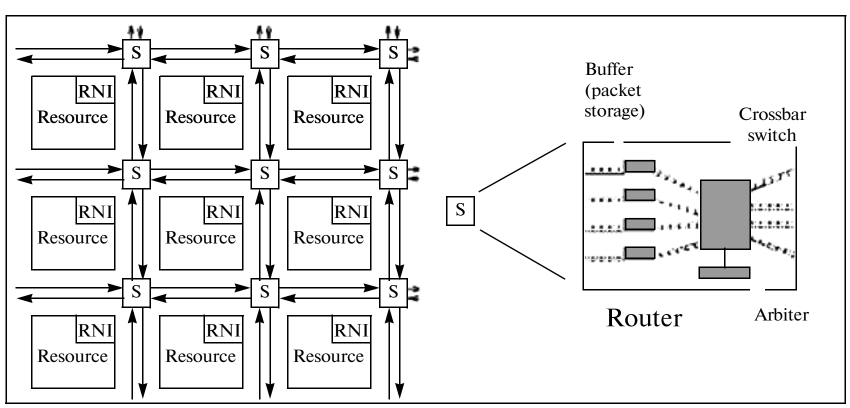


Fig. 10. Network on a chip with 9 nodes (left); each node S represents a router with 4 inputs and outputs (right).

Figure 9 shows an example of a complex circuit: a so-called network on a chip (NoC) [10]. A single crystal houses a lot of familiar elements: the central processing unit (CPU); the memory (MEM); the input/output (I/O); and the USB interface, Ethernet, and others. They mainly communicate using buses, but the question that relates to the topic of this article is how to build the central part—the switching network between the buses.

2.5. The Intel example. The switching element of the modern NoC reaches considerable dimensions. As an illustration of the state of the microelectronics, we refer to the latest development of the Intel company [11]. In February 2014, Intel announced the development of a phenomenal chip that contains a network consisting of a matrix of 256 nodes (switching field of 16 × 16). This network is a high-performance hybrid switch board with 202 terabit/s bandwidth. This chip is based on 22-nm trigate CMOS technology. It is important that this chip is able to switch not only packets (which is standard now) but circuits as well.

2.6. Packet switching (PS NoC). Figure 10 shows an NoC network for packet switching. Each node S comprising a 4 × 4 switch board is a router; it has four inputs, four outputs, and a certain resource (CPU, memory, I/O device) that communicates with the S node via the resource network interface (RNI). In the packet switching (PS) mode, there is a buffer allocated for each input. The operations of the S node are controlled by Arbiter. The operation of message sending is the consistent transmission of packets through a chain of routers.

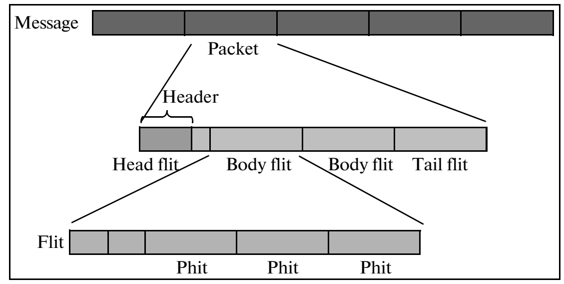


Fig. 11. Dividing messages into shorter pieces while the message is transmitted by the chip [10].

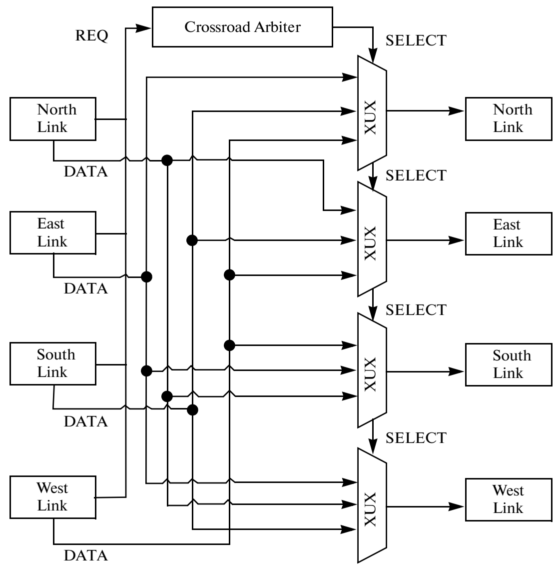


Fig. 12. The switching process in a single node of the switching field.

Figure 11 illustrates the mechanism for transmitting messages received by the chip input. Next, they are divided into smaller parts due to the numbers of bits for the devices (usually, that is the number of parallel wires between blocks). The messages are divided into packets and those in turn are divided into smaller units: Flit and Phit (usually, the lengths of Flit and Phit are the same). Phit is a unit of data that is transferred between nodes in a single cycle of the chip.

2.7. Circuit switching (CS NoC). In the circuit switched (CS) mode, the physical channel (from the network input to the output) is reserved until data transmission starts. When the message subject is being transmitted through the network, it reserves (occupies) the path for the message transmission. Furthermore, this method, as compared with packet switching, eliminates the need to transmit the service information (head flit and tail flit) for each packet.

The essence of circuit switching is explained in Fig. 12: the Arbiter controller determines the bit stream (Phit) in this cycle of the chip.

So, let us summarize the features of CS NoC and PS NoC. In circuit switching mode, there are the following:

• A physical channel (from the network entry to exit) is reserved before starting the transmission of data.

• When the message header is being transmitted through the network, it reserves (occupies) the path for the message transmission.

• The main benefit is low latency in message transmission after reserving the channel.

• Disadvantages are the path continues to be unavailable during the stage of reserving and freeing the channel after the completion of the transmission, and the network in CS mode cannot be scaled with sufficient flexibility.

MPEG-4 decoder in NoC CS and PS NoC embodiments—solutions comparison

	CS NoC	PS NoC
Surface (μm^2)	56.26×10^3	649.27×10^3
Power consumption (μW)	260.6	11793.69
Delay (ns)/switch	3.48	29.66
Bandwidth (10^6 ns)	2.16	12.04

In packet switching mode, there are the following:

- Packets can be transmitted in different ways and can come with different delays.
- Each package should be complemented with service information (head flit and tail flit).
- Transmission starting takes no time, and the delay is variable, which leads to collisions in routers.
- It is difficult to meet the QoS requirements.

We present the results of the first substantial experiments on comparing the CS NoC and PS NoC capacity.

2.8. On CS NOC advantages: MPEG-4 decoder (Taiwan) [12]. Let's start with a specific mass product—an MPEG-4 decoder. The international standard MPEG-4 was introduced in 1998. The MPEG-4 standard is mainly used for broadcasting (video streaming), recording movies onto a CD, and for video telephony (videophones) and broadcasting, which actively use digital video and audio compression.

In 2006, the engineers of a Taiwan university presented MPEG-4 decoder prototypes in two implementations: CS NoC and PS NoC based on 0.18 μm technology. The test results clearly show the advantage of circuit switching for NoC. The CS NoC option surpasses PS NoC in all the indices (table). The most notable is the difference in power consumption—by 45 times. Figure 13 provides the comparison of CS NoC and PS NoC in energy consumption and in latency: the CS mode clearly surpasses the PS mode in energy consumption. The same is observed for the latency—up to 15 switches in the switch field.

2.9. On CS NOC advantages: the Royal Institute of Technology experiment. In 2013, Swedish engineers [13] presented the results of comparing three NoC solutions:

(1) CS NoC with a 4 × 4 switching field;

(2) PS NoC with the same field: 4 virtual channels and 4 buffers (ps_v4_b4); and

(3) PS NoC: 16 virtual channels and 16 buffers (ps_v16_b16).

The measurements have shown (Fig. 14) that, in a vast range of loads, circuit-switched CS NoC is more effective. If the packets are longer than 500–800 bytes, then circuit-switched CS NoC is more effective. The first packet switching PS NoC option (ps_v4_b4) has the advantage only in case of packets of only 500 bytes, while the second PS NoC option (ps_v16_b16) retains its advantage for packet lengths up to 800 bytes. At a packet length of 5120 bytes, the capacity of both PS NoC options is the same.

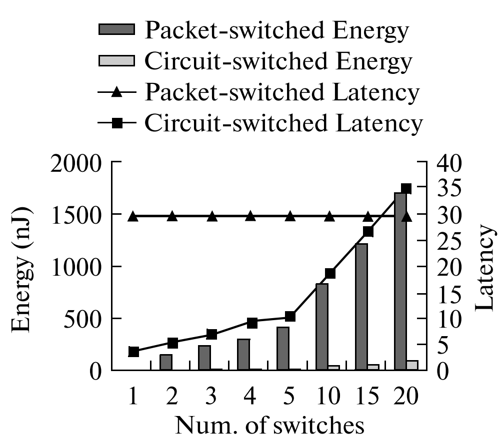


Fig. 13. CS NoC and PS NoC energy consumption and latency comparison.

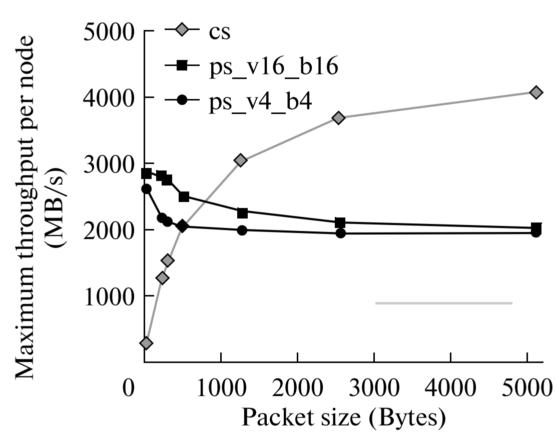


Fig. 14. In a vast range of loads, circuit-switched CS NoC is more effective than packet-switched PS NoC.

The other results of the CS and PS NoC comparison can be found in [14]. In the field of networks on chips (NoC), the principle of packet switching still dominates, but the given examples allow one to predict the return to "forgotten" circuit switching.

3. DISCUSSION

The principle of circuit switching shows its advantage in two ways:

(1) There is an abundance of traditional telephone exchanges and major departmental communication networks around the world built on the traditional telephone circuit switching technology, and they "do not want to die." We have provided an example, the world's largest departmental communication system belonging to the United States DoD, which, in the last decade, has acquired an abundance of packet switching devices but still retains a core of traditional phone stations using SS7 signaling and the principles of an advanced intelligent network (AIN).

(2) In the rapidly developing field of microelectronics and network on a chip (NoC), the advantage of CS NoC compared to PS NoC is manifested in the abundance of products (such as MPEG codecs) that surround us in everyday life. It seems that both technologies—circuit switching and packet switching—will coexist for a long time yet.

The parallels between the traditional telephone exchanges and networks on chips open a new field of mathematical research. Such an attempt is presented in [15] containing examples of calculations regarding packet switching microchips performed by four methods: queue theory, network theory, schedule analysis, and data flow analysis.

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