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On circuit switching revival: from General Shalikashvili and Bell Labs heritage (1998) to Intel's 20.2 Tb/s network-on-chip (2014)

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***Abstract*— The main goal of the paper is to discuss the world telecommunications strategy in transition to the IP world. We start from a short analyse of US Department of Defense obsolete (channel switching oriented) information networks and the announced plans to implement Software Defined Network and Network Function Virtualization. As a case, we are passing through two generations of American military communications: (1) The implementation of signaling protocol SS7 and Advanced Intelligent Network, (2) Transformation from SS7 to IP protocol and comparing two strategic programs: Joint Vision 2010 and Joint Vision 2020. We discuss technology trends in routers and switches and show circuit-switching advantages versus packet switching in the modern field of Network-on-a-chip. We conclude by sentence: circuit-switching equipment could stay for unpredictable time, especially considering cyber security threats.**

***Keywords*- telecommunications; circuit; packet; cybersecurity; network-on-chip**

Abbreviations
AI - Artificial Intelligence
AIN - Advanced Intelligent Network
ATM - asynchronous transfer mode
DISA - Defense Information Systems Agency
DoD - Department of Defense
DoDAF - Department of Defense Architecture Framework
DRSN - Defense Red Switched Network
DSN - Defense Switched Network
DVS - video conferencing network (DISN VIDEO).
GAO - Government Accounting Office
GIG - Global Information Grid
ISDN - Integrated Services Digital Network
JEDI - Joint Enterprise Defense Infrastructure
JIE - Joint Information Environment
JRSS - Joint Regional Security Stack
NFV - Network Function Virtualization
NIPRNet - Non-classified Internet Protocol Router Network
SS7 - signaling protocol #7
SIPRNet - Secret Internet Protocol Router Network
SDN - Software Defined Network
TDM - time division multiplexing

I. Introduction

The main goal of the paper is to discuss the world telecommunications strategy in transition to the IP world. Two-sided difficulties for Information System modernization are meet. From one side, the industry pressure introduces the latest achievements, namely, Software Defined Network and Network Function Virtualization, and from the other, it is difficult to abandon 'old' technologies, as time-division multiplexing, asynchronous transfer mode equipment, signaling protocol SS7 and Advanced Intelligent Network.

On DoD obsolete information networks: the AT&T view. According to the AT&T experts' view [1], the Department of Defense (DoD) today still has analog, fixed, premises-based, time-division multiplexing (TDM) and even asynchronous transfer mode (ATM) infrastructure that drains billions of dollars in legacy operations and maintenance expenses from the DoD's annual budget, while unnecessarily exposing the DoD to cybersecurity risks. This aging network architecture is based on point-to-point circuits that require constant hardware maintenance and upgrades.

The current situation is partially a result of defense contracting, not network providers. The roughly 15,000 separate networks that comprise the DoD's network were built by hundreds of different companies that are not in the business of networking. "*The existing TDM environment is 30 years behind current commercial technologies*", - such is the harsh rebuke of AT&T [1].

US Army Regulator fights for IP technology. The similar kind harsh sentence of the DoD's activities flows from the Army Regulation document [2] of 2017 regarding Telecommunications Systems and Services. The Army regulator recognizes that there is 'old' equipment on the network: Time-division multiplex equipment, Integrated services digital networking, channel switching Video telecommunication services. All these services will use IP technology. Name the few of instructive claims:

4–2.d. Commands that have requirements to purchase or replace existing Multilevel Secure Voice (previously known as Defense Red Switched Network (DRSN)) switches will provide a detailed justification and impact statement to the CIO/G–6 review authority.

4–2.e. The moratorium on investment in legacy voice switching equipment and the requirement to submit requests for waivers to purchase voice-switching equipment applies to all TDM voice-switching equipment that is not capable of providing unclassified and/or secret IP voice services. The

Army will migrate as soon as practical to an almost-everything-over-Internet Protocol architecture, to include Unified Capabilities (UC) and collaboration, with an end state of end-to-end IP.

4–4. All Army organizations will cease investment in (nonemergency) integrated services digital network (ISDN) sup-ported technology, equipment, and transport. All Army organizations will transition from ISDN to a compatible IP-supported technology or service including, but not limited to, video, facsimile, voice, and other network capabilities.

7–4. Secret IP voice is the Army-preferred means of providing secret-only voice communications. The latest UCR will provide guidance for implementation of secret IP voice capabilities. The UCR requires that classified IP voice migrate to multivendor equipment using the Assured Services Session Initiation Protocol (AS–SIP).

The DISA dizzying projects. Under the industry pressure, the DISA administration is oriented officially to the today's top technologies: Software Defined Network and Network Function Virtualization (Fig. 1). According to the newer DISA projects [3] [4], the obsolete TDM technology should be changed by IP technology in the nearest years (Table 1).

Honesty speaking, these DISA projects look unlikely to implement in such short time (they may be even harmful essentially - due to growing cyber threats).

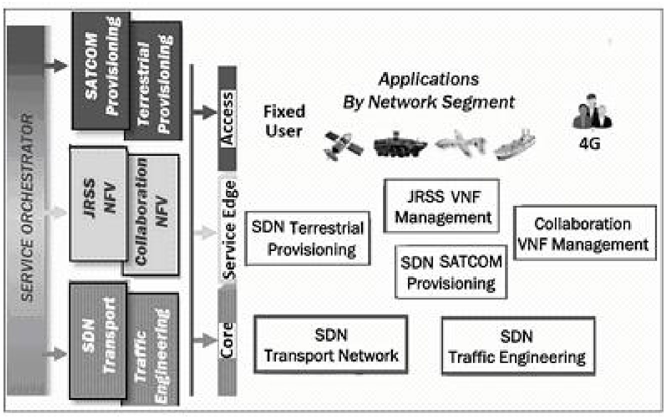

Fig. 1: The newer DISN architecture (the excerpt from slide 8 [3]) Software Defined Network (SDN) & Network Function Virtualization (NFV)

Table 1. DISA Top Priorities (the excerpt from DISN Infrastructure Network Portfolio [3])

DISN Enhancements	Software Defined Network Next Generation Optical Network Trans-Oceanic Upgrades	FY2018 FY2018 FY2018
Legacy Elimination	TDM Elimination SONET/PDH NIPRNet Virtualized Routing and Forwarding SIPRNet Access Migration Defense Red Switch Network – TDM to IP	4QFY2020 FY2019 FY2018 FY2018
DISN Technology Refreshment	Enterprise & Enterprise Classified Voice over IP (VoIP) Secure Communications Interoperability Protocol (SCIP) Gateway Voice Internet Service Provider (ISP) SIPRNET Refresh (Ethernet Security Specification)	FY2018 FY2018 FY2020 FY2018

The rest paper is organized as follows. Section 2 is about Joint Vision 2010, namely, about telephone signaling protocol SS7 and Advanced Intelligent Network developed by Bell Labs, in another words, about channel switching technology. In Section 3, we discuss differences between routers and switches. In Section 4, we refer to Network-on-a-chip technology and some cases on channel switching versus packet switching. We conclude by sentence: TDM and ISDN equipment, obviously, could stay for unpredictable time, especially considering cyber security threats.

II. Joint Vision 2010: General Shalikashvili and Bell Labs heritage

On the initial Shalikashvili's doctrine. The DoD Doctrine [5] issued by General J. Shalikashvili[1] in 1995 is the keystone document for Command, Control, Communications, and Computer (C4) systems up to now. "*The development of DISN will be an evolutionary process that will support the military's move into the 21st century information age, and will replace the individual legacy communications systems with a seamless transport,"* – has ordered General Shalikashvili at the beginning of his service as the Chairman of the Joint Chiefs of Staff.

In those years, the DISN architecture was ATM oriented (Fig. 2).Recall about what is ATM - for young generation readers. Using ATM, information is segmented into fixed length cells [6]. The ATM cell has a fixed length of 53 bytes. A cell is made up of a 'header' and a 'payload.' The payload (48 bytes) being the portion which carries the information to be transmitted (voice, data, video) and the header (5 bytes) being the addressing mechanism. ATM is a switched based technology. ATM was formulated in the early 1980's, as a result of AT&T and French Telecompany's research. ATM was standardised in 1988. ATM is a cell switching technology and along with synchronous digital hierarchy (SDH) transport, was meant to form the basis of the public broadband ISDN (B-ISDN).

As mentioned above by AT&T critics, two highly important classified military networks are built on ATM switches: (1) JWICS (Joint Worldwide Intelligence Communications System), and (2) AFSCN (Air Force Satellite Control Network). They do not like to change anything: do not touch what works!

[1] John Shalikashvili (1936 – 2011) is a man of extremely amazing fate. He served in every level of unit command from platoon to division. Served as a United States Army Supreme Allied Commander Europe from 1992 to 1993. Shalikashvili was the first foreign-born man to become Chairman of the Joint Chiefs of Staff (from 1993 to 1997). He was born in Warsaw, Poland, in the family of émigré Georgian officer Dimitri Shalikashvili and his Russian origin wife Countess Maria Rüdiger-Belyaeva.

"Joint Vision 2010" criticism from the GAO side. In 1996, General Shalikashvili approved "Joint Vision 2010" - a strategic development plan for US military departments for a 15-year period. “Joint Vision 2010” was focused on achieving dominance across the range of military operations through the application of new operational concepts.

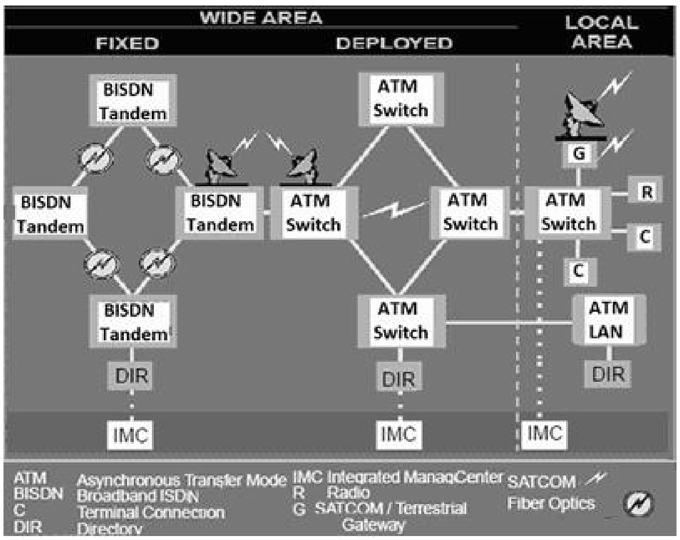

Fig. 2. Key Elements of the DISN Architecture (1995) [6]

"Joint Vision 2010" met harsh criticism from the US General Accounting Office side just in 1998 [7]. The GAO pointed out the following: “*Although Defense has been implementing the DISN program for 7 years, numerous networks continue to exist without DISA’s knowledge. Our own survey found that the military services are operating at least 87 independent networks that support a variety of long-haul telecommunications requirements.”*

As it follows from DoD Response [7], dated May 5, 1997, the DISA experts made an attempt to save ATM solution. Nevertheless, two months later GAO [8] once more noted that:

(1) DOD faces many challenges in achieving its information superiority goals and objectives and may need many years of concerted effort to reach them;

(2) one of the key challenges is to complete the development of a C4ISR[2] architecture, maintain it, and ensure that the many systems that make up the C4ISR infrastructure comply with the architecture.

“*C4ISR architecture is critical to achieving information superiority. Creating the C4ISR Architecture in itself is not enough to build the Defense Information Infrastructure and its attendant systems. Past architecture efforts are not successful,”* - was the GAO conclusion.

[2] C4ISR stands for C4 (Command, Control, Computers, Communications), Intelligence, Surveillance, and Reconnaissance.

DOD has had an official requirement for C4ISR interoperability and for a Department-wide architecture since 1967, when it encountered communications interoperability problems during the Vietnam War: “*However, it has never adequately met that requirement, even though it experienced similar problems during military operations in Grenada, Panama, and the Persian Gulf. In 1987/12 and again in 1993/13 we reported that DOD had made little progress in meeting the requirement because it lacked centralized or joint managerial and funding control over individual service priorities, which often took precedence over interoperability priorities. We also reported that all of DOD's component commands, services, and agencies had been unable to agree on what such an architecture should accomplish or what it should consist of.”* [8]

The fateful DISA decision. In reality, at that time many shortcomings of military information networks had revealed. First of all this was the low level of integration of many hundreds of networks included in DISN, which significantly limits interaction within a single network and hampers effective unified management of all its resources. Under conditions of technological uncertainty, DISA (Defense Information Systems Agency) has made a principled decision to build US military communications networks using the "open architecture" and commercial-off-the-shelf (COTS) products. As a result, the choice fell on the "old" developments of Bell Labs, namely, on the telephone signaling protocol SS7 and the Advanced Intelligent Network (AIN). Note that SS7 protocols had been developed at Bell Labs since 1975 and in 1981 were defined as ITU standards.

The details we found in one paper from Lockheed Martin Missiles & Space [9] – the well-known Defense contractor. Military communication systems have started to merge traditional circuit-switched voice with Internet and Asynchronous Transfer Mode (ATM) as the backbone networks. A critical role of SS7 issue is the interface for voice circuits with ATM.

SS7 is an architecture for performing out-of-band signaling in support of the call establishment, routing, and information exchange functions of the Publish Switch Telephone Network (PSTN). It identifies functions be performed by a signaling system network and a protocol to enable their performance.

In own order, the Advanced Intelligent Network (AIN) was originally designed as a critical tool to offer sophisticated services such as expert operator assistance and directory assistance. The functional structure of the SS7 makes it possible to create the AIN by putting together functional parts.

Fig. 3 describes the AIN components that operate in the worldwide telecommunication network, as well as how they are deployed in SS7 backbone, the space Wide Area Network (WAN), circuit switched voice network and the packet switched terrestrial WAN. The AIN components include the Service Creation Environment (SCE), Service Management System (SMS), Service Control Point (SCP), Service

Switching Point (SSP), Intelligent Peripheral (IP), Adjunct, and the Network Access Point (NAP).

The SCE provides design and implementation tools needed to assist in creating and customizing services in the SCP. The SMS is a database management system used to manage the master database that controls the AIN warfighter services. These services include ongoing database maintenance, backup and recovery, log management, and audit trails. The Intelligent Peripheral (IP) services include:

- Tone generation
- Voice recognition
- Audio and data playback
- Voice or Data compression
- Call control
- Recording
- DTMF tone detection and collection
- Many other tactical or strategic services such as personel identification

The Adjunct provides the same operation as the SCP, but is configured for one or fewer services for a single switch. The Network Access Point (NAP) is a switch that has no AIN functions. It is connected off a SSP, and interfaces to trunks with SS7 messages. It will route the call to its attached SSP or AIN services based on the called and calling number received.

SS7 has been a huge success in the telecommunication industry and is deployed in all public telephone circuit switched networks by all carriers throughout the world. The key features of SS7 have found their way into other systems such as Global System for Mobile Communication (GSM), military communication, and even satellite signaling (Fig. 3).

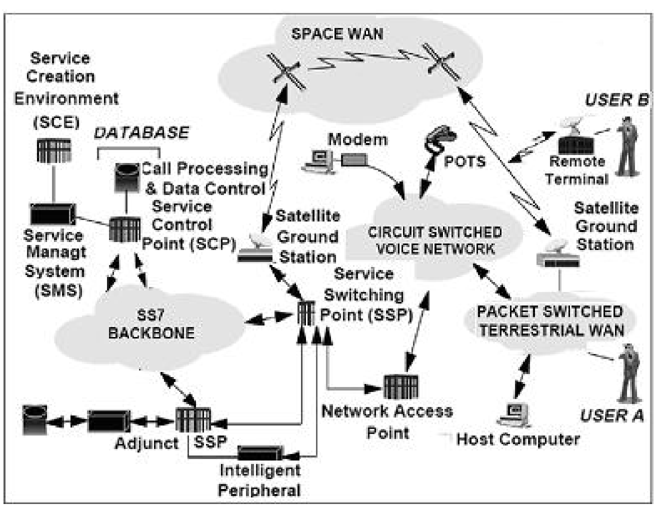

Fig. 3. Advanced Intelligent Network Architecture [9]

The current state of DISN. To illustrate the current DISN architecture we discuss the certification of Avaya S8300D by DISA Joint Interoperability Test Command in 2012 [10]. The tested Avaya S8300D is a Private Branch Exchange (PBX). Its Media Server provides a Voice over Internet Protocol (VoIP)-based integrated voice mail messaging capability for up to 450 light duty users. Each G450 gateway can support up to 8 Digital Transmission Link Level 1 (T1)/European Basic Multiplex Rate (E1) interfaces, can support IP, analog, digital, and Integrated Services Digital Network (ISDN) Basic Rate Interface (BRI) lines in any combination as long as the total doesn't exceed the maximum capacity. The capacities include 8 media module slots, maximum of 450 IP lines, 192 digital/analog lines, 128 BRI lines. The Avaya S8300D supports a maximum of 50 G450 gateways.

The DISN architecture is a two-level network hierarchy consisting of DISN backbone switches and Service/Agency installation switches. The DISN architecture; therefore, consists of several categories of switches including PBXs. The Unified Capabilities Requirements (UCR) operational DISN Architecture test configuration has shown in Fig. 4. Here MFS – Multifunctional switch stands for electronic exchange.

The PBX testing is extremely complicated. Table 2 is an excerpt from as many as 153 testing requirements, including the US and European interfaces (as NATO Allies). This Table gives some insight in a huge volume of software work to be done at transition to the IP technology.

Joint Vision 2020 failure. In 2017 [11], we try to trace the process of DISA transition to IP protocol.

Firstly, in 2007, Pentagon published a fundamental program Joint Vision 2020 [12], which contains the strong requirement: DISN must be built on basis of IP protocol as the only means of communication between the transport layer and applications.

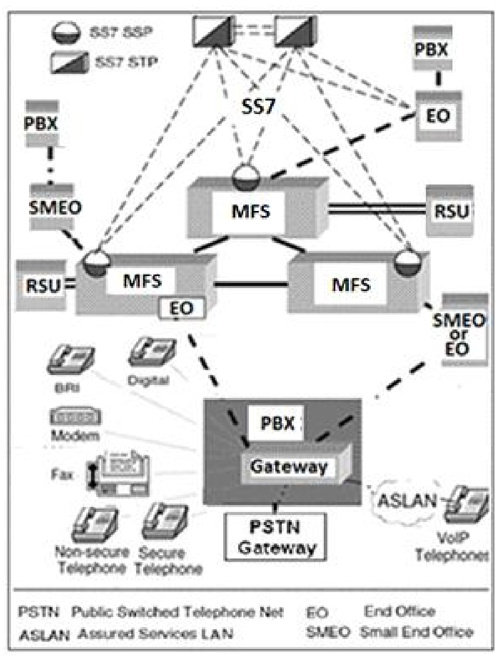

Fig. 4. The simplified DISN view [10]

Secondly. The main drawbacks of the SIP protocol are the difficulties in securing secrecy (under cyber warfare) and servicing priority calls, which is important for military applications, for emergency service. Therefore, by order of the Department of Defense, a secure AS-SIP protocol was developed [13]. The AS-SIP protocol turned out to be very cumbersome. If ordinary SIP uses 11 other RFC standards, then AS-SIP uses the services of almost 200 RFC standards.

Table 2. DISN PBX trunk interfaces (the excerpt from [10]

Interface	Requirements Required or Conditional
T1 CAS (MFR1, DTMF, DP) E1 CAS (MFR1, DTMF, DP) T1 ISDN PRI NI 1/2 (ANSI T1.619a) E1 ISDN PRI (ITU-T Q.955.3)	PBX Line (C) Direct Inward Dialing (C) National ISDN 1/2 Primary Access (R) ISDN ANSI MLPP Service Capability (R) ITU-T ISDN Primary Access (Europe only) (C) System Number 1 MLPP (Europe only) (C) Normal Wink Start Operations (R) Glare Operation (R) Abnormal Wink Start (R) Glare Resolution (R) Call for Service Timing (R) Guard Timing (R) Satellite Timing (R) Disconnect Control (R) Reselect and Retrial (R) Off-Hook Supervision Transition (R) Dial-Pulse Signals (R) DTMF Signaling (R) Standard Digit Format for Precedence (C) MFR1 2/6 Signaling (C) Alerting Signals and Tones (R) DISN ISDN User-to-Network Signaling (R)

Thirdly. The transition from the circuit switched network, where the SS7 protocol prevails, to packet switching and AS-SIP requires the installation of Multifunctional SoftSwitches (MFSS). The MFSS has two important functions: it controls the negotiation of the SIP and SS7 signaling protocols (through the SGW gateway) and converts IP packets to TDM sendings (via the MGW gateway).

Fourthly. Note the leading role of the Session Controller as an essential part of MFSS. The Session Controller is the most complex software package that performs the same functions in packet switching networks as traditional telephone exchange. To implement the all currently existing services and a plenty protocols (see e.g. Table 3 and Unified Capabilities Reference Architecture of 295 pages [6]), Session Controller contains as many as 19 servers for different services.

The target architecture of the future DISN network contains two levels: Tier 0 and Tier 1 (Fig. 5). The Tier 0 cluster is responsible for the invulnerability of the entire DISN network. It contains three Tier 0 softswitches connected by the ICCS (Intra-Cluster Communication Signaling) protocol, which automatically updates their databases.

A cluster is essentially one distributed softswitch. It is required that the delay in the exchange of database contents does not exceed 40 ms. Since the signal transmission takes 6 microseconds per 1 km, the distance between softswiches cannot exceed 6,600 km (1,860 miles). At the lower, second level of the DISN network, Tier 1, there are two types of local networks: a secure ASLAN using the AS-SIP protocol and a traditional LAN using the H.323 protocol (for video conferences). Thus, the secure hybrid network DISN provides voice and video over IP.

It is still difficult to predict the time during which the DISN network will finally switch to the AS-SIP protocol, to switch off from the path initialized by General Shalikashvili and his program Joint Vision 2010.

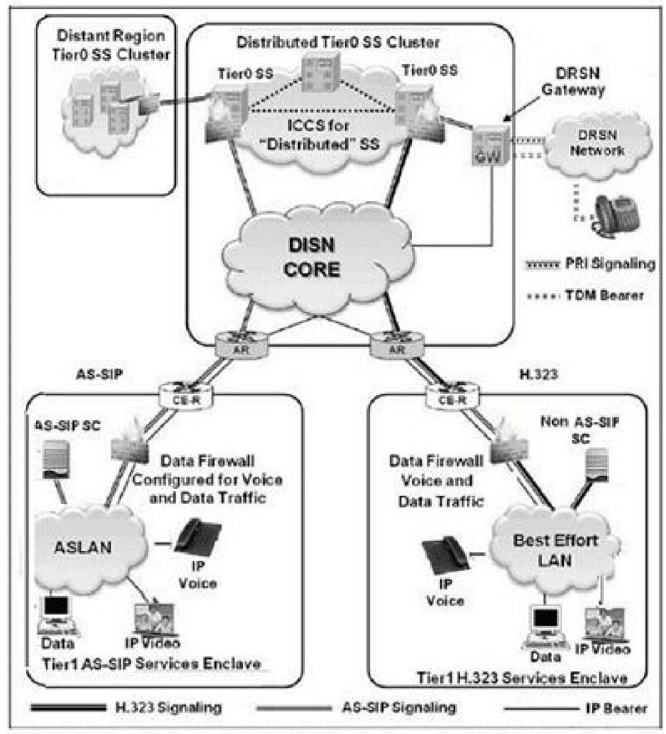

Fig. 5. The target architecture of DISN [14]

III. Technology trends in routers and switches

In order to understand the technology trends [15], one has to know the functions that packet and circuit switches do, and the technology used to perform them. Fig. 6 shows the functional blocks of a packet switch, also called a router. When information arrives at the ingress linecard, the framing module extracts the incoming packet from the link-level frame. The packet then has to go through a route lookup to determine its next hop, and the egress port. Right after the lookup, any required operations on the packet fields are performed, such as decrementing the Time-To-Live (TTL) field, updating the packet checksum, and processing any IP options. After these operations, the packet is sent to the egress port using the router's interconnect, which is rescheduled every packet time. Several packets destined to the same egress port could arrive at the same time. Thus, any conflicting packets have to be queued in the ingress port, the output port, or both.

In the output linecard, some routers perform additional scheduling that is used to police or shape traffic, so that quality of service (QoS) guarantees are not violated. Finally, the packet is placed in a link frame and sent to the next hop. In addition to the data path, routers have a control path that is used to populate the routing table, to set up the parameters in the QoS scheduler, and to manage the router in general. The signaling of the control channel is in-band, using packets just as in the data channel. The control plane might obtain the signaling information through a special port attached to interconnect.

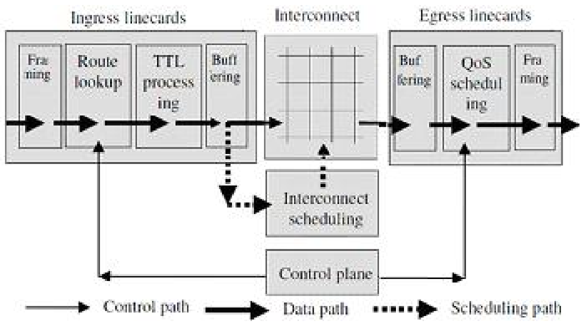

Fig. 6. Functionality of a packet switch [15]

The main distinction between a router and a circuit switch is when information may arrive to the switch. In packet switching, packets may come at any time, and so routers resolve any conflicts among the packets by buffering them. In contrast, in circuit switching information belonging to a flow can only arrive in a pre-determined channel, which is reserved exclusively for that particular flow. No conflicts or unscheduled arrivals occur, which allows circuit switches to do away with buffering, the on-line scheduling of interconnect, and most of the data-path processing. Fig. 7 shows the equivalent functions in a circuit switch. As one can see, the data path is much simpler.

In contrast, the control plane becomes more complex: it requires new signaling for the management of circuits, state associated with the circuits, and the off-line scheduling of the arrivals based on the free slots in the interconnect. Usually there is a tradeoff between the signaling/state overhead and the control that we desire over traffic: the tighter the control, the more signaling and state that will be needed. However, in circuit switching, as in packet switching, a slowdown in the control plane does not directly affect the data plane, as all on-going information transmissions can continue at full speed. In general, its data path determines the capacity of the switch.

Another important difference between a router and a circuit switch is the time scale in which similar functions need to be performed. For example, in both types of switches the interconnect needs to be scheduled. A packet switch needs to do it for every packet slot, while a circuit switch only does it when new flows arrive.

The transition from TDM technology to IP switches brings the extra software expenditures (Table 3). Compare two large TDM and packet switches of the same bandwidth – 640 Gbps (10 million TDM calls simultaneously): the operation systems demonstrate the significant difference – up to three times (in reality, 10 times in cost).

Table 3. Comparison of TDM and packet switches, 2012 [22].

	TDM Switch	Packet Switch
	Ciena CoreDirector	Cisco CSR-1
Bandwidth	640 Gbps	640 Gbps
Power	1440 W	9630 W
Software (M lines)	3 M lines	8 M lines
Price	$84, 000	$884, 000

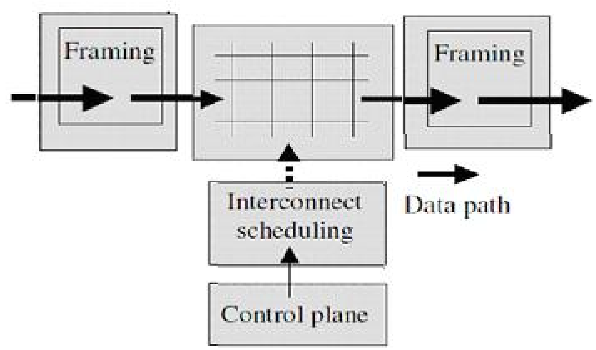

Fig. 7. Functionality of a circuit switch [15]

VI. Network-on-a-chip: CS versus PS

NoC basics. 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.

Packet switching (PS NoC). Fig. 8 shows a NoC network for packet switching. Each node S comprising a 4x4 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 S node is controlled by Arbiter. The operation of message sending is the consistent transmission of packets through a chain of routers.

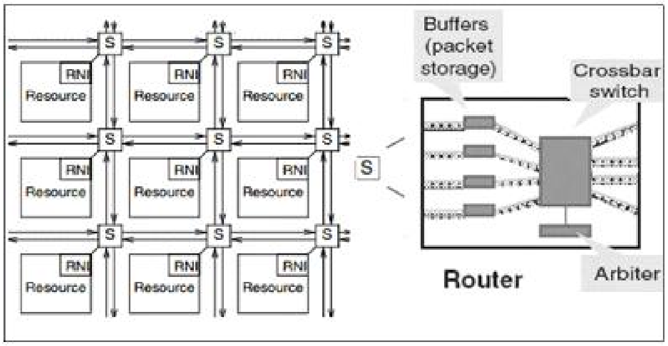

Fig. 8. Network on a chip with nine nodes (left); each node S represents a router with 4 inputs and outputs (right)

What is the mechanism for transmitting messages received by the chip input. 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 - Flits. Flit is a unit of data that is transferred between nodes in a single cycle of the chip.

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 the following: the Arbiter controller determines the input, and the multiplexer, the output of the bit stream (Flit) in this cycle of the chip.

Summarize the features of CS NoC and PS NoC. In circuit switching mode, there are the following steps:

(1) a physical channel (from the network entry to exit) is reserved before starting the transmission of data;

(2) when the message subject is being transmitted through the network, it reserves (occupies) the path for the message transmission;

(3) the main benefit is low latency in message transmission after reserving the channel.

Disadvantage is 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.

In packet switching mode, there are the following steps:

(1) packets can be transmitted in different ways and can come with different delays;

(2) each package should be complemented with service information (head flit and tail flit);

(3) transmission starting takes no time, and the delay is variable, which leads to collisions in routers;

(4) it is difficult to meet the QoS requirements.

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

On CS NOC advantages: MPEG-4 decoder (Taiwan). 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 [16]. The test results clearly show the advantage of circuit switching for NoC. The CS NoC option surpasses PS NoC in all the indices (Table 4). The most notable is the difference in power consumption — by 45 times.

Table 4. Experimental results for two different MPEG-4 decoder architectures [16]

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

From the experimental results, we see that the delay of one packet-switched router is much larger than that of the switch because the former one consists of several complex components for processing packets. From these figures we conclude that although the packet-switched NOC is high performance and high throughput, the area and the power consumption will significant increased when the scale of the network increases.

In summary, major advantages of the proposed circuit-switched interconnection architecture are lower power consumption, lower communication latency than that of the packet-switched NOC. If the scale of the SOC is just under few tens of cores, using the proposed circuit-switched NOC will be more attractive than the packet-switched NOC.

On CS NOC advantages: a Stockholm experience. In 2013, Swedish engineers (the Royal Institute of Technology, Sweden) presented the results of comparing three NoC solutions [17]: (1) CS NoC with a 4 x 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. 9) 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 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.

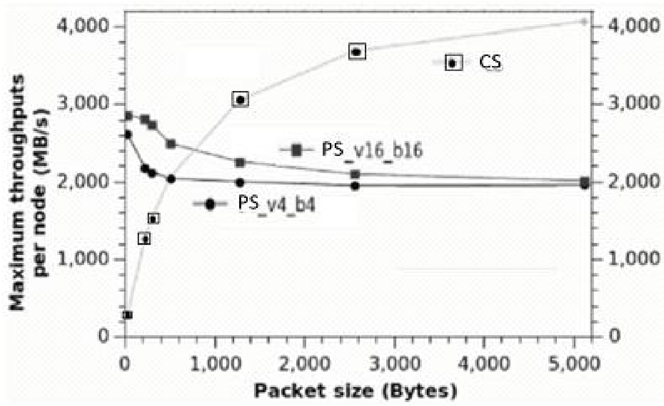

Fig. 9. In a vast range of loads, circuit-switched CS NoC is more effective than packet-switched PS NoC [17]

Intel's crazy efficient, crazy fast network-on-chip. In February 2014 [18], Intel announced the development of a phenomenal chip that contains a network consisting of a matrix of 256 nodes (16 × 16 mesh network-on-chip). This network is a high-performance hybrid switchboard with 20.2 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 (as a standard now) but circuits as well.

The Intel's NoC achieves (Fig. 10) the following:

- 20.2 Tb/s total throughput at 0.9 V, 25 °C;
- source-synchronous operation for a 2.7× increase in bisection bandwidth to 2.8 Tb/s and 93% reduction in circuit-switched latency at 407 ps/hop, compared to synchronous design;
- hybrid packet/circuit switching for a 62% latency improvement and 55% increase in energy efficiency to 7.0 Tb/s/W, compared to packet switching;
- a peak energy efficiency of 18.3 Tb/s/W for near-threshold operation at 430 mV, 25 °C;
- ultra-low-voltage operation down to 340 mV, 25 °C, with router power scaling to 363 μW.

Hybrid circuit-switched router as intelligent network prototype. The paper [19] proposes a hybrid circuit-switched router that interleaves circuit- and packet-switched flits on the same physical network with low area and power overhead. Combining SDM and TDM techniques in a router (Fig. 11) allows taking advantages of the abundance of wires resulting from the increased level of CMOS circuits. We then have two degrees of freedom to optimize the router; one can increase either the number of subchannels in an SDM-TDM Channel or the number of time slots per subchannel. In both cases, the number of available channels increases in the network, thereby increasing the possibilities of establishing paths through the network.

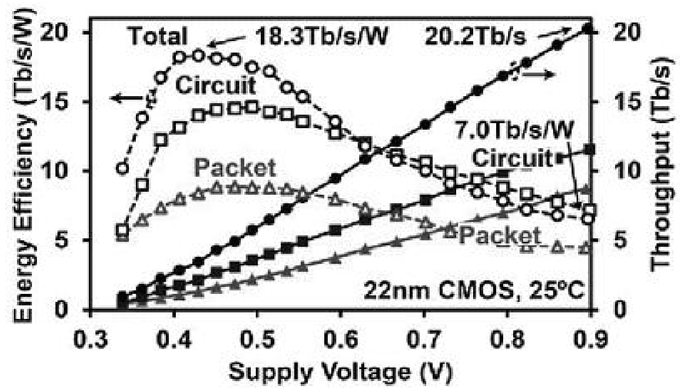

Fig. 10. Voltage scaling and throughput measurements [18]

At the router (2,3), the allocator LOCAL reserves the requested time slot at the unique subchannel; in this case, it is the time slot number 3. The ACK packet is then generated and routed through the packet-switched subrouter from the destination to the source. Upon reception of the ACK packet, the source node then starts transferring streaming data at the time slot specified by the allocator EAST at router (2,1). Fig. 11 shows the established path and the scheduling of time slots. 7 × 7 mesh NoCs were simulated in SystemC.

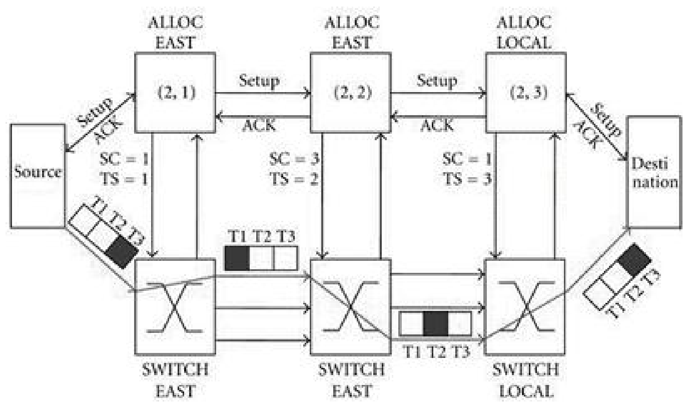

Fig. 11. SDM-TDM path between source (2,1) and destination (2,3) [19]

This NoC recalls the Intelligent Network architecture. The upper part is similar to the packet switching SS7 network, the bottom part is channel switched network (see Fig. 4).

In 2015, the telecommunications world was shocked by the news: Lockheed Martin is not coping with the upgrade of the DISN network management and sells its division "LM Information and Global Solutions" to the competing firm Leidos. The failure of the work was most likely due to the inability to recruit developers capable of combining the "old" circuit switching equipment with the latest packet switching systems as well as taking into account the new cybersecurity requirements.

V. Conclusion: Don’t Touch What Works

On of Defense Information Systems Agency (DISA) ambitions. The DISN architecture prescribes a global network integrating existing defense assets, military satellite communications, commercial satellite communications initiatives, leased telecommunications services, as well as the dedicated worldwide enterprise-level telecommunications infrastructure that provides the interoperable transport for the end-to-end transfer of information in support of military operations.

What GAO Found. However, In October of 2018, Government Accounting Office (GAO) has reported [20], the United States weapons systems developed between 2012 and 2017 have severe, even “mission critical” cyber vulnerabilities, and that the federal information security (i.e. cybersecurity) needs to improve “the abilities to detect, respond to, and mitigate cyber incidents”, increase its cyber workforce and increase cybersecurity training efforts.

What is the DoD’s answer regard cyber threats? The Defense Department's newly released cloud strategy positions the general-purpose Joint Enterprise Defense Infrastructure (JEDI) cloud initiative as the foundation [21]. JEDI is not DoD's first foray into cloud computing. The Pentagon already is a multi-cloud environment. There are some 500 clouds in operation across DoD’s various offices, agencies and departments. One of the largest of these is the milCloud, managed by the Defense Information Systems Agency (DISA). This is really a great idea – cloud computing with artificial intelligence based, if it happens to be successful.

ISDN-based government network DRSN. No reason to be surprised that the Defense Red Switch Network (DRSN) uses 40 years old ISDN technology (Fig. 12). It looks as some kind of birthmark in the IP environment. DRSN is a dedicated telephone network, which provides global secure communication services for the command and control structure of the United States Armed Forces and NATO Allies. The network is maintained by DISA and is secured for communications up to the level of Top Secret SCI.

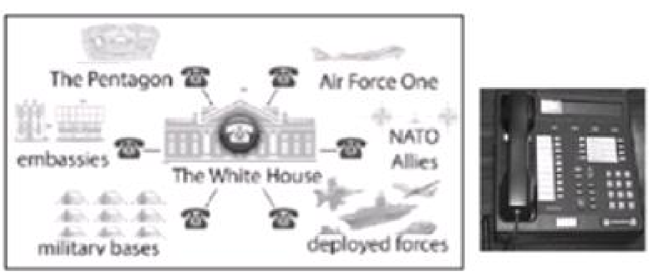

Fig. 12. Scheme of the government network DRSN and Red phone

What does follow from the Army Regulation official document [2]? Obviously, TDM and ISDN equipment could stay for unpredictable time, especially considering cyber security threats. Look at Red phones. These devices are tens of thousands all over the world and are rather costly. How to replace all them within a year and most likely because of vendors thirst to earn? Reasonable to call: Do not touch what works!

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