

Time to Rethink the Power of Packet Switching

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Abstract—Communication specialists all around the world are facing the same problem: shifting from circuit switching (CS) to packet switching (PS). 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 the move to hybrid CS+PS solutions. We are considering three areas: (1) network-on-a-chip (NoC), (2) the telecom strategy: how to build the core of the network, (3) the transition of the U.S. Defense Information System Network from SS7 signaling to IP protocol.

I. INTRODUCTION

Communication specialists around the world are facing the same problem: shifting from circuit switching to packet switching. We will provide examples to illustrate the difficulties that complicate the transition from CS to PS and the move to hybrid CS+PS solutions. We are considering three areas.

In Section II, a new trend in microelectronics, namely, a network-on-a-chip (NoC) orientation from packet switching to circuit switching is considered. Section III is devoted to the telecom strategy: to use packet switching at the edges of the network and circuit switching at the core of the network. In Sections IV and V the transition of the U.S. DISN (Defense Information System Network) from SS7 signaling to IP protocol is discussed. In 2006, the Pentagon adopted a new plan for the next 15 years entitled Joint Vision 2020. The plan announced a DISN paradigm shift: the transition from SS7 signaling to IP protocol. It is assumed that the IP protocol will be the only means of communication between the transport layer and applications. But... a sort of birthmarks on the DISN remains: the "Red Phone" network (Defense Red Switched Network) is based on ISDN technology.

Therefore, the long CS and PS co-existence seems inevitable.

II. NETWORK-ON-A-CHIP: ON HYBRID CS+PS VERSION

Consider the confrontation of CS and PS supporters in one particular but very important area, namely — microelectronics. NoC schemes were 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. 1 shows an example of a complex circuit: a so called network on a chip (NoC) [1]. 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.

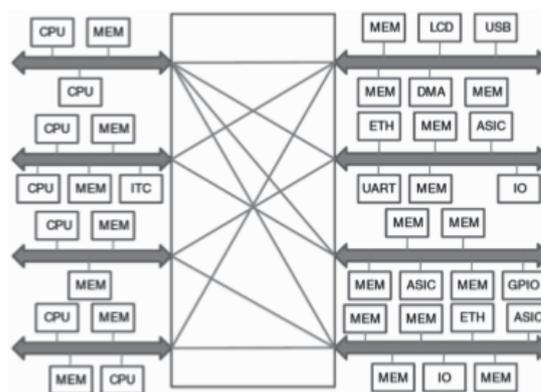


Fig. 1. Single-crystal microchip (NoC) example [1]

A phenomenal Intel chip. 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 Intel [2]. In February 2014, Intel announced the development of that contains a network consisting of a matrix of 256 nodes (switching field of 16 x 16). This network is a high-performance hybrid switchboard 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 (as a standard now) but circuits as well.

Packet switching (PS NoC). Fig. 2 shows a NoC scheme for packet switching. Each node S comprising a 4x4 switchboard 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 mode, there is a buffer allocated for each input. The operations of S node are controlled by Arbiter. The operation of message sending is the consistent transmission of packets through a chain of routers.

Fig. 3 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 (often, the lengths of Flit and Phit are the same). Phit is a unit of data transferred between nodes in a single cycle of the chip.

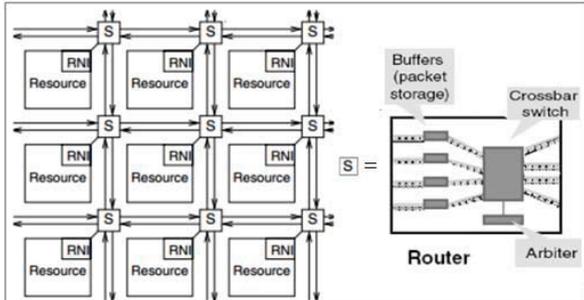


Fig. 2. Network on a chip with 9 nodes (left); each node S represents a router with 4 inputs and outputs (right)

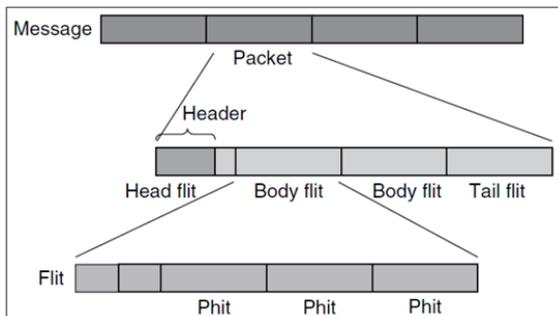


Fig. 3. Dividing messages into shorter pieces while the message is transmitted by the chip

Circuit switching (CS NoC). In the 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.

On CS NOC advantages: MPEG-4 decoder (Taiwan). Let's start with a specific mass product — an MPEG-4 decoder. The MPEG-4 standard (introduced in 1998) is used mainly 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 [3]. The test results clearly show the advantage of circuit switching for NoC. The CS NoC option surpasses PS NoC in all the indices (Table I). The most notable is the difference in power consumption — by 45 times.

In the PS NOC, the latency means the time of transmitting one message from one node (router or PU) to another node passing through a router. In circuit-switched NOC, the latency means the time of transmitting one message from one core to

another core passing through switches. From the experimental results, we see that the delay of one PS router is much larger than that of the switch because the former one consists of several complex components for processing packets.

TABLE I. RESULTS FOR TWO DIFFERENT MPEG-4 DECODER ARCHITECTURES [3]

	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 summary, the advantages of packet-switched NOC are scalability and high throughput, however, they still suffer from long end-to-end latency, high implementation costs and unnecessary power consumption. 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.

Hybrid circuit-switched router. The paper [4] proposes a hybrid circuit-switched router that interleaves circuit- and packet-switched flits on the same physical network with low area and power overhead. Network design for CMPs is an area of significant research effort.

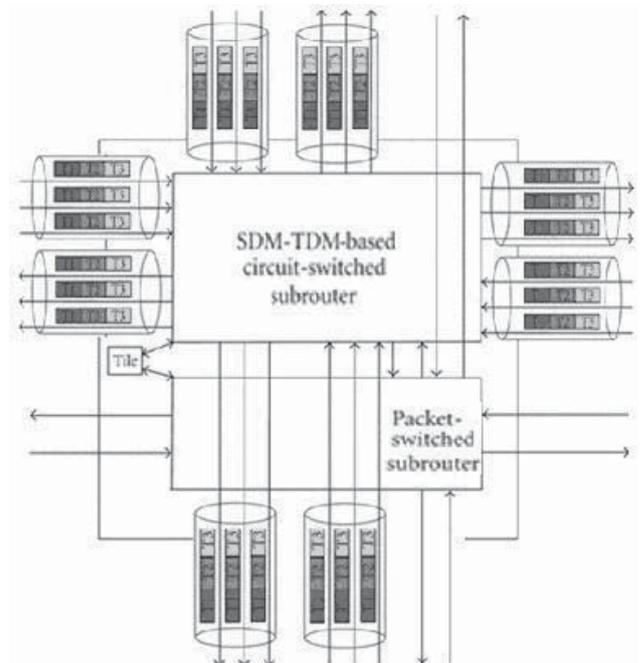


Fig. 4. Hybrid SDM-TDM router architecture [4]

Combining SDM and TDM techniques in a router (Fig. 4) 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.

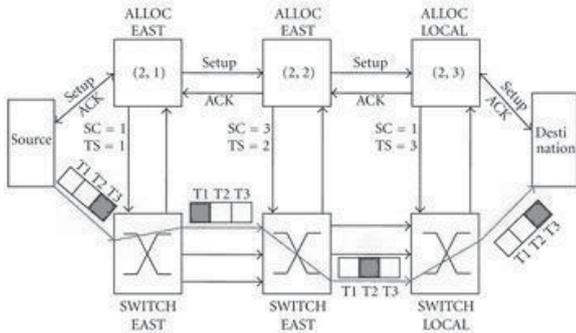


Fig. 5. SDM-TDM path between source (2,1) and destination (2,3) [4]

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. 5 shows the established path and the scheduling of time slots.

The proposed hybrid router architectures were synthesized. Results show that a practicable NoC can be built using the proposed router architectures. 7×7 mesh NoCs were simulated in SystemC. Simulation results show that the probability of establishing paths through the NoC increases with the number of sub-channels and has its highest value when combining SDM with TDM, thereby significantly reducing contention in the NoC.

On CS+PS NoC co-existence. For NoC survey see [5]. In papers [6, 7], a hybrid router architecture, which combines an SDM-based circuit switching with packet switching for on-chip networks is proposed. The SDM-based circuit-switched subrouter is responsible for handling streaming traffic, while a packet-switched subrouter is responsible for handling the best-effort traffic.

The work [8] demonstrates the potential of circuit-switched networks for multi-core architectures. Hybrid circuit switching is able to reduce network latency by up to 23% and improve overall performance by up to 7%; when combined with our protocol optimizations overall performance improves by up to 15%. HCS (Hybrid Circuit-Switch) achieves these performance gains over a highly optimized baseline packet-switched router with single-cycle delay for low-loads.

III. COMMENTS ON FUTURE CIRCUIT SWITCHING TECHNOLOGY FROM STANFORD UNIVERSITY

Comparison of packet and circuit switching. In order to study how the capacity of links and switches will scale in the future, one needs to understand the evolution trends of the underlying technologies used in routers and circuit switches. This enables one to foresee where bottlenecks might occur [9]. The first potential bottleneck is the memory system, the second one is information processing. Comparing the switches of equal throughput, it is reasonable to expect that since packet switches

do much more, it would come at the cost power and price. In [10] two high capacity switches are compared: packet switch Cisco CRS-1 and Ciena TDM switch; the former consumes 7 times the power and costs 10 times more. The software running in a typical transport switch is based on about three million lines of source code, whereas Cisco's Internet Operating System (IOS) is based on eight million, over three times as many.

The key question is: will the packet-switched IP network grow to dominate and displace the circuit switched transport network; or will the (enhanced) circuit-switched TDM and optical switches continue to dominate the core transport network?

If we are looking for simplicity, we can do well to look at how circuit-switched transport switches are built. First, the software is simpler. The software running in a typical transport switch is based on about three million lines of source code, whereas Cisco's Internet Operating System (IOS) is based on eight million, over twice as many. Table II explains the complexity of router (packet switch).

TABLE II. COMPARISON OF PACKET AND CIRCUIT SWITCHING FUNCTIONS [10]

TDM Switch	Packet Switch
Phy	Phy Policing
TSI	Parsing Policy Routing
Fabric	Lookup Congestion Avoidance
	Modifications QoS
	Fabric Sampling & Mirroring
	ACLs Hashing
	Queuing

At the core of the network, we expect the circuit switched transport network to remain as a means to interconnect the packet switched routers, and as a means to provide high reliability, and performance guarantees. Over time, more and more optical technology will be introduced into the transport network, leading to capacities that electronic routers cannot achieve.

The hybrid packet and circuit core network. An another case coming also from Stanford University [11] and co-authored by prof. Nick McKeown, the inventor of SDN technology, relates to AT&T US IP core network (Fig. 6).

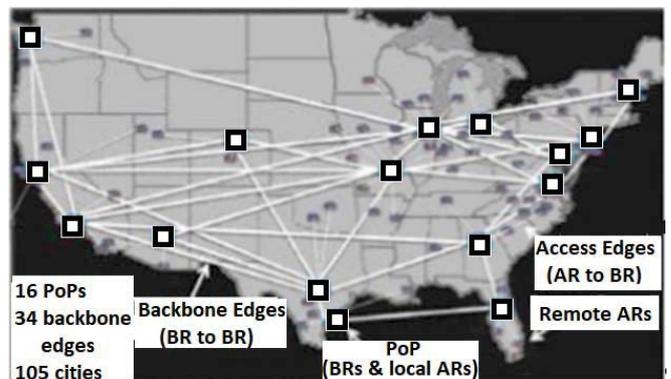


Fig. 6. AT&T US IP core network: 16 PoPs across the U.S. are aggregating the traffic from 89 other cities

They have compared two architectures: (1) traditional All-IP version used MPLS backbone routers (BR) and (2) the hybrid packet and circuit core with hybrid MPLS-OTN (packet optical) switch, building on the ideas from SDN (Fig. 7). The basic idea is to keep all transit traffic in the circuit domain during normal operation as well as during failures. They propose not just a reduction, but the complete elimination of all core-facing BR ports, and replace the BRs with hybrid switches that have both packet-switching and optical-switching fabrics in nearly equal measure. All of the packet switching in the hybrid switch happens on the interfaces to the AR, and the ARs continue to be dual homed to the hybrid switch. All of the core-facing ports are optically circuit switched.

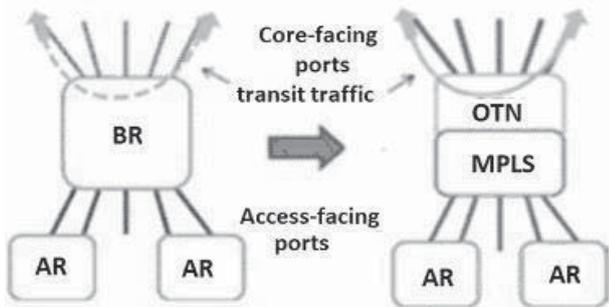


Fig. 7. Replacing BRs in core PoPs with hybrid MPLS-OTN switches

The overall number of core ports was reduced significantly in IP-and-DCS (Dynamic Circuit Switching) when compared to the reference design (from 2564 to 1480). As a result, nearly 60% in overall Capex savings have been achieved when compared to the reference IP-over-WDM design (Fig. 8). Most of these savings come in the backbone switches, which see an 85% reduction in cost.

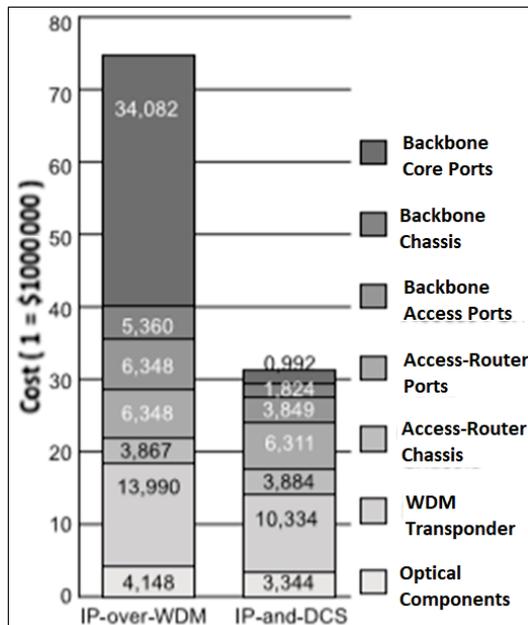


Fig. 8. Capex results for two AT&T US IP core network designs [11]

While there have been many proposals for hybrid packet and circuit-switched backbone networks, the authors [11] believe this is the first to use an SDN control plane to control both

packets and circuits, and therefore allow the use of a low-cost, full-mesh optical network to serve as the core of an IP network. They also believe it is the first comprehensive cost analysis of a new approach.

These results have led to the following:

(1) Packet switching will continue to exist at the edge of the network. The packet-switched network should ideally gather traffic from disparate sources, and multiplex it together.

(2) At the core of the network, the circuit switched transport network should remain as a means to interconnect the packet switched routers, and as a means to provide high reliability and performance guarantees.

IV. DIGITAL TRANSFORMATION OF DISN

The SS7 network is, figuratively speaking, the nervous system of a DISN (Defense Information System Network) network up to recent time. Fig. 9 originates from the documentation on testing the SS7 network as the part of the DISN network conducted by Tekelec in 2011 [12]. The center of the diagram is occupied by the SS7 network undergoing the test. That is, within the DISN network, the connections are established by means of SS7 signaling and, in the periphery, devices of any type are used.

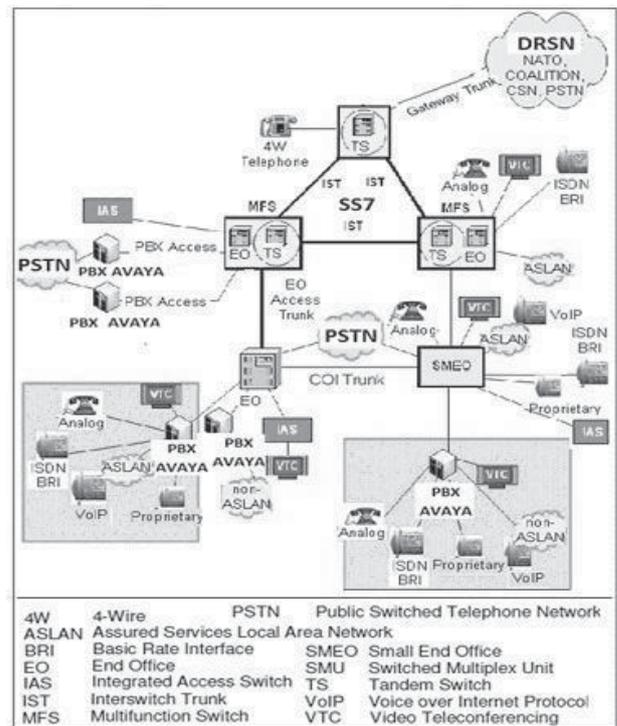


Fig. 9. DISN: the current state [12]

The DISN devices are connected by any protocols: 4-wire (4W); classified LAN (ASLAN); ISDN BRI; Internet telephony (VoIP); video conferencing (VTC); any proprietary protocol. From above an important conclusion follows: the DISN network tends to adopt new terminal equipment (in a large extent, this is IP media), but the SS7 network retains its central position till now. The presence of the SS7 network is not an obstacle to the transition to IP protocol.

The most important step for DISN modernization is the replacing of channel switching electronic Multifunctional switches (MFS) by packet switching routers. The transition phase is based on use of Multifunctional SoftSwitches.

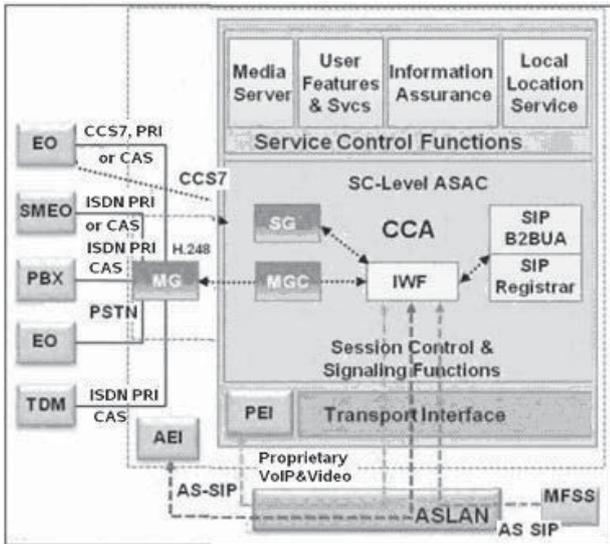


Fig. 10. Reference model for Multifunction SoftSwitch (MFSS) [13]

Fig. 10 shows the reference model for MFSS. The left side shows the traditional telephony protocols CCS7, ISDN PRI, and CAS (Channel Associated Signaling) used for connections with the “old” channel switching networks. MFSS interfaces the circuitswitched based external TDM network and the IP backbone network will also control the calls that are originating from the external Public Switched Telecommunications Network (PSTN)/Integrated Services Digital Network (ISDN). So, MFSS will also needs to provide ISUP-SIP inter-networking function (IWF). It is expected that TDM switching portion of the MFSS will be retired as soon as all users/systems migrate to IP [14].

A signaling gateway (SG) deals with all signaling protocols such as ISUP, CCS7/SS7, and CAS. The MFSS also operates as a media gateway (MG) between TDM circuits switching and IP packet switching under the control of the media gateway controller (MGC) while communications control protocol like H.248 is used between MG and MGC.

V. THE TARGET DISN INFRASTRUCTURE

The target DISN infrastructure contains two level switching nodes: Tier0 and Tier1. Tier0 geographic cluster typically consists of at least three Tier0 SoftSwitches (SSs). As the distance between the clustered SSs must be planned so that the RTT does not exceed 40 ms and propagation delay equals 6 μs/km thus distance between Tier0 should not exceed 6,600 km. The classified signaling environment is unique in that it will use a mix of existing vendor-based H.323 and AS-SIP signaling during the transition period to all DISN CVVoIP (Classified VoIP and Video). In addition, a unique MG capability exists as part of a Tier0 SS.

The classified Voice and Video Signaling Design is shown in Fig. 11 [3]. Currently, the classified voice and video

services employ H.323. They will migrate to AS-SIP signaling in the future. Duration migration, both H.323 and AS-SIP signaling will be employed in classified VVoIP. Classified VVoIP interfaces to the TDM Defense RED Switch Network (DRSN) via a proprietary PRI. The Common Channel Signaling 7 (CCS7) network is being phased out and replaced by PRI trunks. The TDM End Offices (EOs) use PRI for signaling to the TDM switching part of the softswitch.

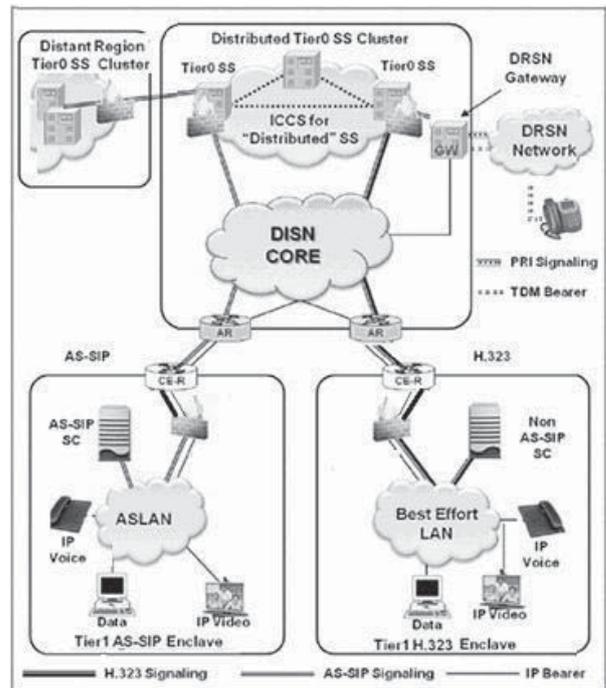


Fig. 11. DISN Classified VoIP and Video (CVVoIP) Signaling Design

The softswitches use AS-SIP between themselves to set up IP-to-IP EI sessions across the DISN IP WAN. During a transition period, H.323 and AS-SIP will coexist at certain locations. Thus, CAS and PRI in the DRSN has to interoperate with H.323 signaling in the VoSIP Pilot to be followed by H.323 and AS-SIP interoperating in the CVVoIP system until all IP services are via AS-SIP.

The DRSN is designed to ensure four priority classes: these call attempts by "directly connected" special users will be completed on a non-blocking basis. RED switches must comply with the DRSN interface criteria and only connect to the DRSN with the approval of the Joint Staff [5]. Special DRSN security features include Automatic Number Identification (ANI), Security Access Levels, Automatic Security Authentication (ASA) and Push-to-Talk Handset.

The STU-III/STE (Fig. 12) is the primary device for enabling secure communications over the DSN. It may be used for secure voice, data, video, or facsimile. The DRSN provides high-quality secure-voice services, data, voice conferencing, and the ability to provide other value added services to senior decision makers. These additional services include, but are not limited to, secure VTC, RED gateway functions for wireless and voice-over-Internet Protocol, and strategic-to-tactical secure-voice interoperability.

The Defense Red Switch Network (Red phone network) is based on ISDN technology. It is some kind of birthmark in the environment of AS-SIP. DRSN is a dedicated telephone network, which provides global secure communication services for the command and control structure of the United States Armed Forces (Fig. 12).

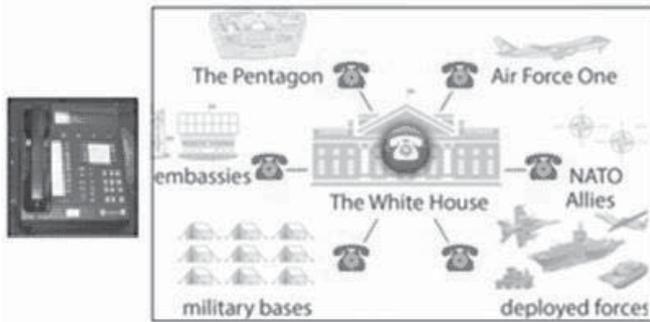


Fig. 12. Secure Terminal Equipment, STE; note slot in front for Crypto PC Card (left). The DRSN architecture (right)

The network is maintained by the Defense Information Systems Agency (DISA) and is secured for communications up to the level of Top Secret SCI. Secure Terminal Equipment (STE) is designed to use ISDN telephone lines 128 Kb/s.

VI. CONCLUSION

The article is devoted to the discussion of the telecommunications development strategy. We will provide examples to illustrate the difficulties that complicate the transition from circuit switching to packet switching, and the move to hybrid CS+PS solutions.

Therefore, the long CS and PS co-existence seems inevitable.

We have considered three areas:

- (1) A new trend in microelectronics: a network-on-a-chip (NoC) orientation from packet switching to circuit switching,
- (2) The telecom strategy: to use packet switching at the edges of the network and circuit switching at the core of the network,
- (3) The transition of the U.S. DISN (Defense Information System Network) from SS7 signaling to IP protocol, but... the "Red Phone" network (Defense Red Switched Network) is still built on ISDN technology.

ACKNOWLEDGMENT

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