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On Some Software-Defined Radio Failures

Manfred Sneps-Sneppe

***Abstract*— The Joint Tactical Radio System (JTRS) should play, as was planned, an important role in the U.S. Army's proposed Future Combat System (FCS) program. Starting in 1997, JTRS was an attempt at unifying military radios by digital signal processing. It is a set of software-defined radios (SDRs). The idea was to use this system as the core element of the FCS to link all of its 18 manned and unmanned systems. This was one extremely ambitious project, and this was a basis for the strategic "Joint Vision-2010" plan oriented to the Network-Centric Warfare concept. In 2009, the FCS program was ceased. One of the reasons for the failure was the immaturity of SDR technology, especially in terms of the MANET concept. Unfortunately, the FCS Network, predicated on a MANET implementation, employing ground and air systems as nodes, was thus being designed without a foundation of fundamental results. The JTRS program was projected to replace the 25 to 30 families of radio systems used in military systems. After 15 years and spending $15 billion, the JTRS program failed to deliver radios to the battlefield and was canceled in October 2011. We are not aware of any attempts to analyze modern state of radio technologies, especially MONET technologies. However, the analysis of the described applications shows that the MANET approach has proven to be the most vulnerable point in military communications. During these past 14 years, SDR technology has matured, thus is thoughtful to hope for a revival of the SDR approach.**

***Keywords:* Software-defined radio, Future combat system, Joint tactical radio system, MANET**

INTRODUCTION. WHAT IS SDR

Software-defined radio (SDR) is a radio communication system where components that conventionally have been implemented in analog hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by the means of software on a computer.

Perhaps the first software-based radio transceiver was designed and implemented by Peter Hoeher and Helmuth Lang at the German Aerospace Research Establishment in Oberpfaffenhofen, Germany, in 1988. In 1995, Stephen Blust coined the term "software-defined radio" at the first meeting of the Modular Multifunction Information Transfer Systems (MMITS) forum in 1996, organized by the DARPA.

The Operating Environment (OE) for mobile radio protocols (called waveforms) as applications allows some separation between waveform applications and radio platforms (Fig. 1). The OE enables to manage waveforms and provides radio platform services (transceiver, modem, etc.).

The idea behind the SDR is that there is a digital signal processor (DSP) that will handle tasks such as baseband signal processing, modulation and demodulation, encoding and decoding, and time synchronization. The DSP module consists of many programmable digital circuits. The latter may include an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), an ordinary processor (in some papers – a general purpose processor or GPP), or a combination of these elements.

ASIC and FPGA are specialized components according to their tasks. ASICs perform down-conversion, digital-filtering, and operate at higher speeds than FPGAs. ASICs are designed for specific purposes and cannot be reprogrammed. This is a specialized device that is more energy efficient (due to its smaller size) than the GPP.

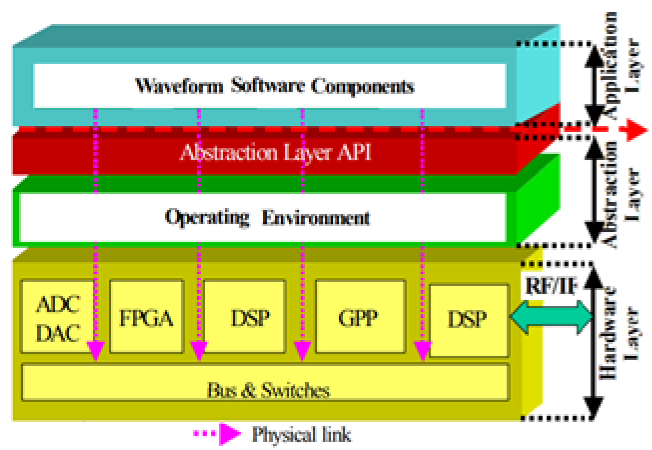

Fig. 1: Distributed SDR architecture [1]

FPGAs are fully programmable devices that can perform a variety of user-defined tasks, including digital down□conversion, signal processing, and filtering. Finally, GPPs are one of the most popular implementations and prototypes of SDRs due to their high level of reconfigurability flexibility. The advantage of using GPP is that here programs are written in high-level languages such as C++. At the same time, specialized devices can outperform conventional processors in energy efficiency. Naturally, to synchronize all elements, you need to be tied to a single time. The synchronization is, usually, a major concern to SDR designers.

Figure 2 shows a typical SDR transceiver structure. It usually contains the following main parts: (1) smart antenna, (2) analog RF interface, (3) digital interface, and (4) digital signal processing unit (Baseband Processing). In this case, the input section uses an analog radio frequency circuit and is responsible for receiving and transmitting a signal at different operating frequencies, connecting the radio station to the antenna or its feeder.

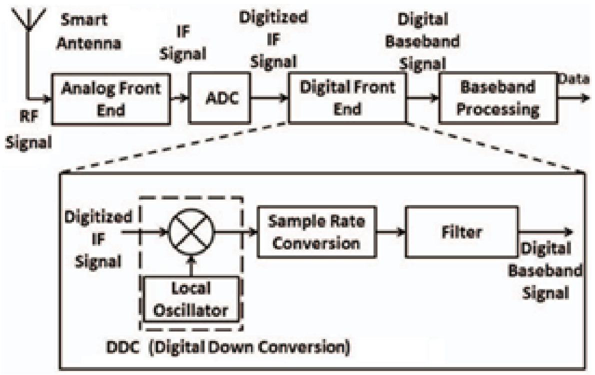

Fig. 2: Software-defined radio transceiver [1]

The following is based on my personal 65-year experience in telecommunications and reflects some further development of the three previous articles [2-4]. Part 1 reflects the vicissitudes of the Pentagon with Future Combat Systems (started in 2003 and ceased in early 2009) and the Joint Tactical Radio System program (launched in 1997 and ceased in 2011). Part 2 contains a brief overview of similar failures of the Russian army.

PART 1. PENTAGON CASE

A. *Joint Vision 2010 and Future Combat Systems*

In 1996 the Pentagon strategy "Joint Vision 2010" [5] was declared: "We must have information superiority: the capability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same. Today, America's Armed Forces are the world standard for military excellence and joint warfighting. We will further strengthen our military capabilities by taking advantage of improved technology and the vitality and innovation of our people to prepare our forces for the 21st century." (Fig. 3)

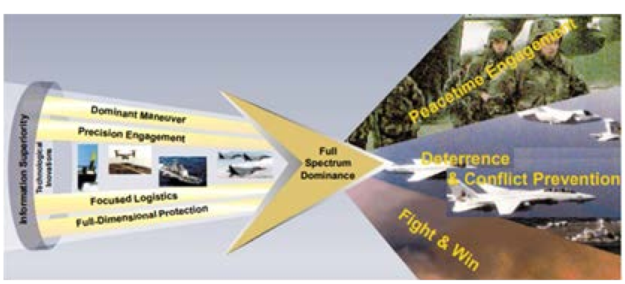

Fig. 3: Full Spectrum Dominance [5]

The Defense Information Systems Agency has made a principled decision - to build US military communications networks using the "old" developments of Bell Labs, namely, the telephone signaling protocol SS7 and the Advanced Intelligent Network (AIN) [6]. SS7 protocols had been developed at Bell Labs since 1975 and in 1981 were defined as ITU standards. (Note that the Bell System was dismembered in 1983.)

The key point of "Joint Vision 2010" was the Future Combat Systems (FCS) as the United States Army's principal modernization program from 2003 to early 2009 (Fig. 4). Formally launched in 2003, FCS was envisioned to create new brigades equipped with new manned and unmanned vehicles linked by an unprecedented fast and flexible battlefield network. The U.S. Army claimed it was their "most ambitious and far-reaching modernization" program since World War II. Between 1995 and 2009, $32 billion was expended on programs such as this, "with little to show for it". What was the reason?

Fig. 4. Initial FCS timeline (1997)

The Joint Tactical Radio System (JTRS) should play, as was planned, an important role in the U.S. Army's proposed Future Combat System (FCS) program [7]. Starting in 1997, JTRS was an attempt at unifying military radios by digital signal processing. It is a set of software-defined radios (SDRs). The idea was to use this system as the core element of the FCS to link all of its 18 manned and unmanned systems (Fig. 5). This was one extremely ambitious project, and this was a basis for the strategic "Joint Vision-2010" plan oriented to the Network-Centric Warfare concept [8]. The JTRS program was projected to replace the 25 to 30 families of radio systems used in military systems.

Fig. 5: FCS's Core Systems (18 systems total). SOSCOE is envisioned to be the network-centric operating system that integrates all separate FCS communications software packages

The Army made several adjustments to its plans for the FCS program [9]. Under the GAO pressure [10] the program was reduced to 14 vehicles (instead of the previous 18). The list of requirements was also excessive – from 544 operational requirements to 80,000 system-level requirements (Fig. 6). It became obvious that there were not enough resources to implement the program.

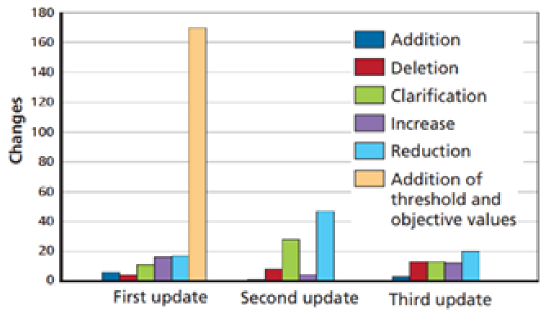

Fig. 6: Requirements Changes by Type from 2005 to 2008

The FCS software development program was the largest in DOD history, and the importance of software needed for FCS performance was unprecedented. Since the FCS program started in 2003, the projected amount of software by 2005 has almost doubled, to 63.8 million lines of code [10]. And more – this huge software was based on a single operational system SOSCOE planned to be ready only by 2011. As a result, in 2009, the FCS program was ceased.

B. Joint Vision 2020 and the turn to "all-over-IP"

Just a few years later, in May 2000, the next strategy "Joint Vision 2020" followed. It builds upon and extends the conceptual template established by "Joint Vision 2010" to guide the continuing transformation of the Armed Forces. This program was oriented on Internet protocols (Figs 7 and 8). The more details contain the "Global Information Grid" document [11].

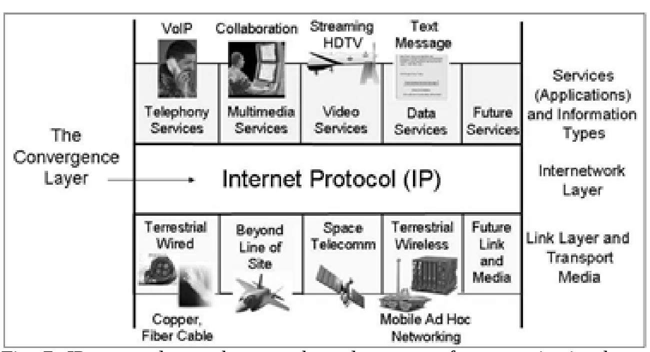

Fig. 7: IP protocol must become the only means of communication between the transport layer and applications (as GIG Internetworking Convergence Layer)

The IP-based communications infrastructure includes terrestrial, space-based, airborne, and wireless segments, instantiated in several key DoD communications programs. Figure 9 depicts the interconnected nature of these segments in the GIG for DoD users (connections to mission partners are not depicted). The terrestrial segment provides a ubiquitous, 'bandwidth-available', environment.

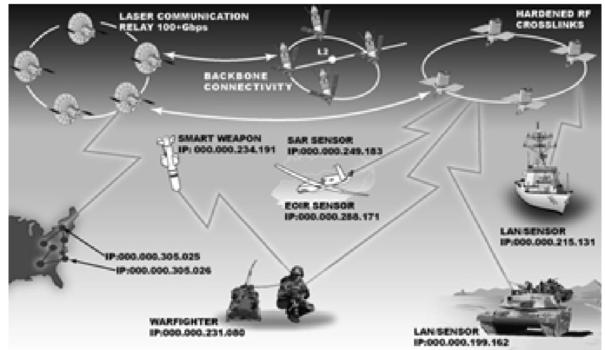

Fig. 8: In a single network, the GIG IP protocol unites everyone: each platform and each sensor have its IP address and are integrated into a single network with the soldier

Most critical facilities are connected with fiber over physically diverse routes using state-of-the-art optical mesh network design. Teleports provide the interface between terrestrial, tactical/theater, and space assets. Tactical gateways and ground stations supplement the Teleports in this interoperability function. Also referred to as "IPv6 and beyond" to reflect the communications capabilities needed to support the target GIG. Gateways may still exist between converged IP and tactical environments.

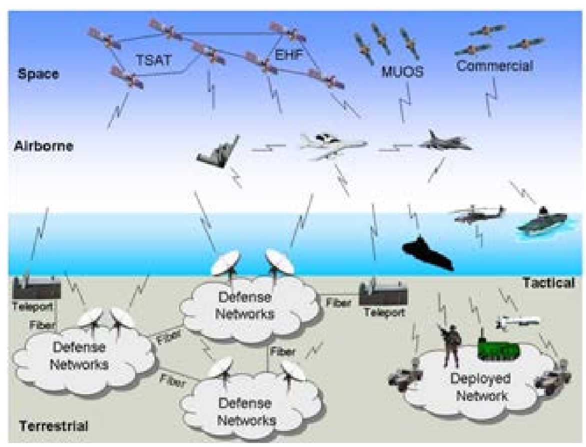

Fig. 9: GIG Communications Infrastructure [11]

The space-based segment includes high-capacity, protected, and advanced IP communications equipment such as the Transformational Satellite (TSAT). The wireless or radio segment (including handhelds, vehicle mounted, airborne, sea-based, and fixed locations) of the tactical environment is primarily based on software-programmable radios such as the Joint Tactical Radio System (JTRS) [12]. This family of software-defined radios is programmable to support interoperability and end-to-end routing across divergent networks.

When the Army started the Future Combat System program in May 2003 three key systems to the FCS communications network were the following:

(1)Joint Tactical Radio System (JTRS), (2) Warfighter Information Network-Tactical (WIN-T), and (3) System of Systems Common Operating Environment (SOSCOE).

JTRS and WIN-T were estimated to cost over $34 billion to develop and produce, from above the $108 billion cost of FCS [10]. The SOSCOE software will reside within each FCS platform's integrated computer system to provide interoperability, information assurance, and communications. According to the Army estimates SOSCOE software development will be completed in 2011. Unfortunately, the complexity of SOSCOE made coordination among Army engineers working on different portions nearly impossible (this was the weak point in the Program).

Let us consider three key FCS communications systems in more detail.

C. Joint Tactical Radio System

The Joint Tactical Radio System (JTRS) aimed to replace existing radios in the American military with a single set of software-defined radios that could have new frequencies and modes ("waveforms") added via upload, instead of requiring multiple radio types in the ground vehicles, and using circuit board swaps to upgrade.

The JTRS program was launched on August 21, 1997, and by a subsequent Operational Requirements Document (ORD) on March 23, 1998 (which was revised several times). The JTRS program started with two types of radios: Ground Mobile Radios (GMR) and Handheld Manpack & Small Form Fit (HMS).

GMR - formerly Cluster 1, run by the Army, was to equip Marine and Army ground vehicles, Air Force Tactical Air Control Parties (TACPs), and Army helicopters. Cluster 1 also included the development of a Wideband Networking Waveform (WNW), a next-generation IP-based waveform designed to allow mobile ad hoc networking (MANET). In 2005, the Air Force TACP and Army helicopter radios were deleted.

HMS - formally Cluster 5, led by the Army, developed handheld, man-portable, and smaller radios.

The JTRS program was led by the Joint Staff and was represented by all four Joint Staff Services. Each team member reported to their Service's chief information officer and reported back to the Joint Staff J6. The ORD started with 38 Threshold waveforms/radios and 4 Objective waveforms to support operations in three domains: Airborne, Maritime, and Ground Forces.

JTRS Network Enterprise Domain (NED) was responsible for the development, sustainment, and enhancement of interoperable networking and legacy software waveforms. NED's product line consists of 21 waveforms:

14 Legacy Waveforms

3 Mobile Ad Hoc Networking Waveforms (MANET)

- Wideband Networking Waveform (WNW)
- Soldier Radio Waveform (SRW)
- Mobile User Objective System ([MUOS–Red Side Processing)

4 Network Enterprise Services (NES)

JTRS was originally planned to use frequencies from 2 megahertz to 2 gigahertz. The addition of the Soldier Radio Waveform (SRW) waveform means the radios will also use high frequencies above 2 GHz [13].

Communication protocols of the JTRS program called waveforms are defined as software applications; the Army was looking at using 19 different waveforms to facilitate JTRS transmissions to current legacy systems. After 15 years and spending $15 billion, the JTRS program failed to deliver radios to the battlefield and was canceled in October 2011. The JTRS project failed the Army's Network Integrated Environment (NIE) testing [14]. Firstly, the NIE exercises have exposed critical failure: sometimes it is necessary to send messages right during the battle, and waiting for the radio to go through a slow series of boot processes (up to several minutes) is completely unacceptable. Now it is clear that SDR was an immature technology. It was applied for the Future Combat Systems – the largest and most ambitious planned acquisition program in the US Army's history. For several years this program was defined as a basis of the modernization effort of the Army. The scope and possibilities of the program were enormously extraordinary. JTRS is widely seen as a key reason for FCS failure, one of the DoD's greatest failures.

D. Warfighter Information Network-Tactical

The GIG Architectural Vision, in combination with other, more detailed descriptions provides the focus for the development of the GIG Capability Increments. Figure 10 illustrates the WIN-T concept (with notional dates).

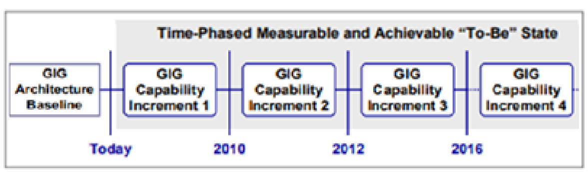

Fig. 10: Transition from GIG Architecture Baseline to GIG Architectural Vision (as planned) [12]

The WIN-T program consists of four increments (as was initially planned):

Increment 1: "Networking At-the-Halt" enables the exchange of voice, video, data, and imagery throughout the tactical battlefield using a Ku- and Ka-satellite-based network. The Army has fielded WIN-T Increment 1 to its operational forces.

Increment 2: "Initial Networking On-the-Move" provides command and control on-the-move down to the company level for maneuver brigades and implements an improved network security architecture. WIN-T Increment 2 supports on-the-move communications for commanders with the addition of the Point-of-Presence (PoP) and provides a mobile network infrastructure with the Tactical Communications Node (TCN).

Increment 3: “Full Networking On-the-Move” provides full mobility command and control for all Army field commanders, from theater to company level. Network reliability and robustness are enhanced with the addition of the air tier transport layer, which consists of networked airborne communications relays.

Increment 4: “Protected Satellite Communications On-the-Move” includes access to the next generation of protected communications satellites while retaining all previous on-the-move capabilities.

The WIN-T program was interrupted in 2011 at the stage of implementing Increment 2. Let us explain the essence of what is happening. WIN-T CS 13 belongs to the second generation of the defense network - WIN-T Increment 2. The main feature is its ability to control combat on the march. Previously, such capabilities did not exist. It was necessary to deploy stationary satellite communications, radio antennas, and cables between devices. In general, the WIN-T CS 13 system is completely delivered by the C-130 aircraft and is quickly deployed after its landing in the deployment area.

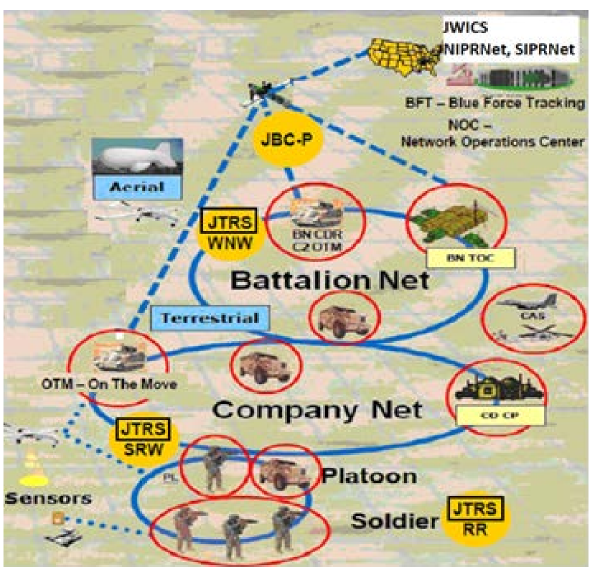

Fig. 11: General view of the WIN-T network. Note three JTRS waveforms [12]

The general view of the WIN-T network is shown in Fig. 11 [12]. The NOC headquarters (in Fig. 11 in the upper right corner) is located, apparently, in Fort Meade (Maryland) and monitors the combat operations of all NATO formations via the WIN-T network (Blue Force Tracking is the name given in the US to NATO units equipped with GPS tracking systems: Blue stands for friendly troops, and Red stands for enemy troops). In addition, three Internet networks are used:

• Joint Worldwide Intelligence Communications System (JWICS) - for transmitting classified information via TCP/IP protocols.

• NIPRNet (Non-classified Internet Protocol Router Network) - a network used to exchange non-classified but important information between "internal" users.

• SIPRNet (Secret Internet Protocol Router Network) - a system of interconnected computer networks used by the Ministry of Defense to transmit classified information via TCP/IP protocols.

Fig. 11 also shows three levels of radio communications equipment: battalion-level wideband JTRS WNW, march-level equipment JTRS SRW, and lightweight battlefield equipment JTRS RR. Figs 12 and 13 illustrate some of the innovations of WIN-T CS 13. It is important to note that the mobile command point WIN-T CS 13 has a connection with the NOC headquarters via the Blue Force Tracking satellite communications unit.

As stated in [12], WIN-T CS 13 is the first fully integrated system that includes radio equipment, a satellite system, a new software package, and a soldier communication device (similar to a smartphone), which provides communication between the stationary command post, the commander on the march and the soldiers.

Fig. 12: Mobile command vehicle WIN-T CS 13 (external appearance)

Fig. 13: Battle control panel

In October 2012 (after ceased of the JTRS program) the US Army embarked on an ambitious upgrade of its tactical command and control system, introducing new radios, networking, and satellite communications systems to modernize the command and control layers of its infantry brigade combat teams. The backbone of this system is the internet-like network supporting forward command posts over broadband satellite links. Capability sets are distributed through the brigades' combat formations, supporting elements from the brigade command post to the commander on the move and the dismounted soldier.

The main elements included in CS-13 [15] are: (1) the General Dynamics C4 (GDC4S) WIN-T Increment 2, (2) Joint Capabilities Release (JCR) Blue Force Tracker 2 from Northrop Grumman, (3) Joint Battle Command Platform, (4) Company Command Post capability, and (5) Mission Command Common Operating Environment v1.0. Consider the content of the main structural components:

E. SOSCOE

The JTRS was built on the Software Communications Architecture (SCA), an open-architecture framework that tells designers how hardware and software are to operate in harmony. It governs the structure and operation of the JTRS, enabling programmable radios to load waveforms, run applications, and be networked into an integrated system. A Core Framework, providing a standard operating environment, must be implemented on every hardware set. Interoperability among radio sets was increased because the same waveform software can be easily ported to all radios.

Software Development Was Very Ambitious. The GAO [16] drew attention to the scope and management of software development. The effort doubled, in terms of lines of code to be written, during the FCS program. The result was a monumental 63 million total lines of code. The Joint Strike Fighter, the next most software-intensive weapon program, needs just a third of this amount. Previous experience indicates that software-intensive programs are more likely to be successful if they follow an evolutionary environment, which the Army was pursuing with FCS. The software deliverables were spread out in four blocks, each adding incremental functionality in eight areas, which the Army further subdivided into 100 smaller and more manageable subsystems. As an illustration of problems with the rapid acquisition strategy, the GAO highlights that the last 10 percent of software delivered and tested will be after the early 2013 production decision. Other key issues were inadequately defined requirements that could hamper desired functionality, as well as a lack of accuracy in estimating the Future Combat Systems Program required lines of code (i.e., level of effort), which could be understated by as much as 70 percent.

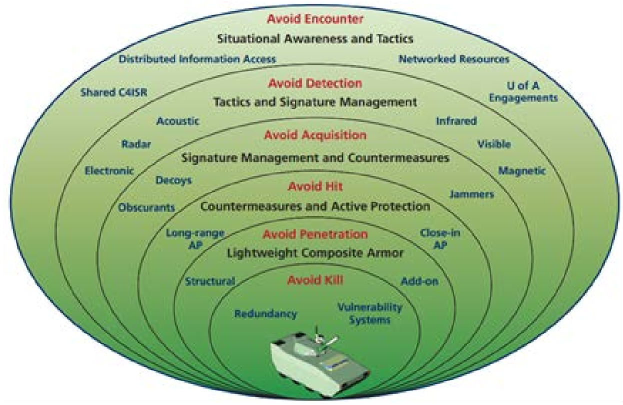

Fig. 14: The FCS Holistic Approach to Survivability illustrates the variety of requirements [16]

The complexity of SOSCOE made coordination among Army engineers working on different portions nearly impossible, and the progress reviews were too detailed to be helpful at a larger functional level (Fig. 14).

The FCS network employed JTRS and WIN-T hardware and a variety of software to control these software-defined radios for network operations. In addition, software applications for battle command and logistics support were hosted on the network through the SOSCOE (System of Systems Common Operating Environment) running on the Integrated Computer System. SOSCOE developed by Boeing is built on top of a COTS Linux operating system. It provides various services, which isolate applications, such as battle command or logistics software, from the details of interacting with the FCS network, providing information assurance and, more generally, low-level or common services that are not application specific. The SOSCOE toolkit includes developer tools, documentation, and runtime software.

SOSCOE comes in three editions, Micro, Real-Time, and Standard with increasing complexity and size to provide scalability across platforms with varied computing resources. Its development was phased in four major builds, with greater functionality added incrementally, and software releases every three months.

Fig. 15: The SOSCOE Approach [17]

To lower the cost of development and maintenance, SOSCOE utilizes open-source, COTS, and GOTS software packages; in build two it had 53 open-source and 14 COTS/GOTS packages. It was initially forecasted to have around 20 million effective software lines of code in its final form. The two following examples illustrate software complexity.

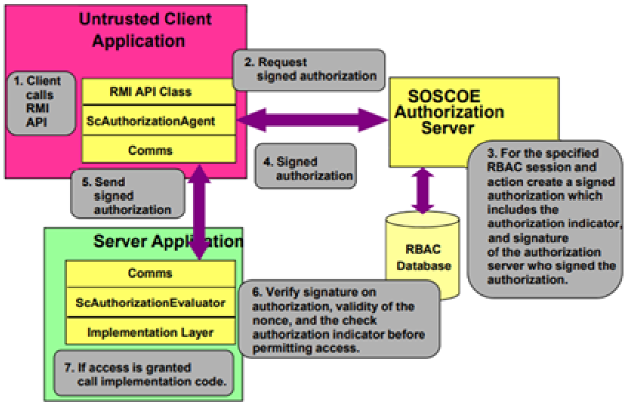

Fig. 16: Information Assurance integrated into the base fabric of user and application interactions [18]

Let us say a few words about software critics, namely about CORBA: the JTRS program was oriented toward elastic and interoperable communications. The failure is the following: SDR systems are based on an open software communications architecture (SCA). This standard uses CORBA on top of the POSIX operating system for inter-module communication. A key failure was the choice of CORBA technology.

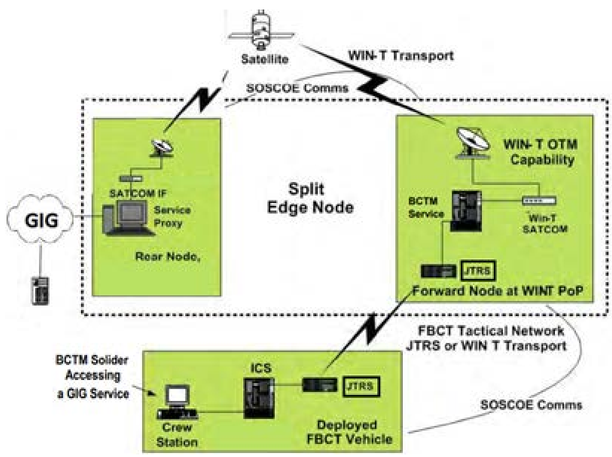

Fig. 17: SOSCOE provides interoperability between Web Services and the Tactical Edge [18]

This technology was originally designed for the portability of RPC applications within distributed systems. The RPC model is built on the untruthful idea that there is a reliable, homogeneous, secure network with zero latency and infinite bandwidth – the more it never changes topology and always has only one administrator. This requirement was unachievable.

F. What are the lessons from the FCS program failure?

The report [19] was written by 12 authors from the RAND Corporation and contains 374 pages. The authors distilled lessons from six aspects of the FCS program: (1) its background; (2) the evolution of cost, schedule, and performance; (3) the requirements process; (4) the program's management; (5) the program's contracts; and (6) the program's associated technology. We here consider only Technology Choices and Development in FCS.

The FCS program was expected to interoperate with many legacy or developmental radio systems, with JTRS and WIN-T being the most well-known. However, FCS struggled for the first two to three years to understand the status of JTRS. Furthermore, the ORD specified JTRS as the primary radio for FCS, discouraging analysis of alternative radios that, although less capable, may have provided some fraction of desired operational capabilities. As a result, FCS depended entirely on the JTRS radios.

The importance of developing an advanced mobile tactical Internet-like network was necessary not only for the FCS concept but also for the wider DoD community. This is the so-called MANET concept.

All networks must communicate information, successfully delivering it from a source to a destination. Mobile Ad-Hoc Networks rely on wireless communication without a stable underlying wired infrastructure, unlike the Internet, which has nodes that are not mobile and rely on a relatively stable fiber optic and telephony copper wire network as the backbone. Attempting to design MANET network protocols, as the rules for optimal communication between nodes, is an immensely challenging technical problem.

Unfortunately, the FCS Network, predicated on a MANET implementation, employing ground and air systems as nodes, was thus being designed without a foundation of fundamental results. In addition to the lack of information theory supporting the MANET concept, operational requirements also posed challenges for a practical realization of a tactical MANET. The challenges of realizing the FCS MANET were discussed by wireless networking experts at the "Science of Networks" conference in 2005 hosted by RAND Arroyo Center. There were four important conclusions derived from this meeting:

1. The science (i.e., theory) of wireless mobile networks is relatively immature.

2. The relatively small number of mobile, wireless networks of today can not scale well to large size (e.g., hundreds or thousands of nodes passing substantial amounts of data).

3. Unprecedented Army networks must be designed through a series of experiments (i.e., trial and error), which FCS was doing.

4. There is no guarantee an experimentally based developmental approach will result in a satisfactory network design.

The June 2008 Independent Review Team conveyed MANET scalability and stability as an unresolved technical challenge, which requires "intensive Program Management," to integrate MANET protocols being developed by JTRS, into the FCS network. A lack of a presently available COTS or

GOTS solution for protecting against intrusion on the tactical MANET was formalized as a risk with high likelihood and consequence. The mitigation plan thus identified the provider of a potential solution, and it consisted of supporting continued research on this effort.

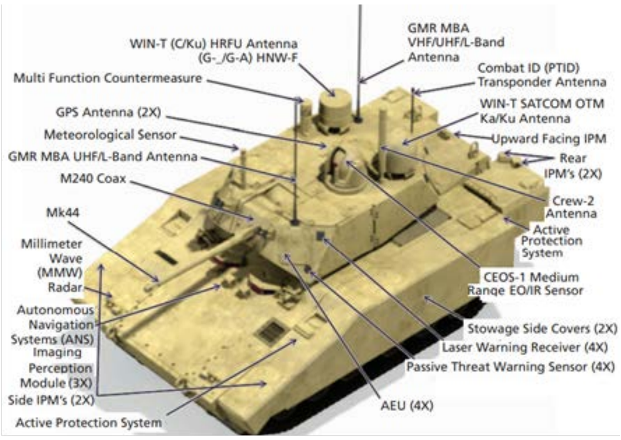

Fig. 18: XM1206 Infantry Combat Vehicle will most closely resemble the Ground Combat Vehicle

One especially troubling aspect of the MANET was that the mobility of some radios would cause the entire network to crash.

The report [19] is concluded by Infantry Combat Vehicle as an example of the software complexity: all more than 30 devices are software-based and before then their requirements are described in detail. This is a mind-boggling complexity. Life has shown that it is beyond the capabilities of the current level of technology, as demonstrated by the failure of the FCS program in 2009.

G. What remains of the ambitious JTRS project?

In 2012 the analysis of Joint Tactical Radio System failure was done in detail in [20].

The AN/PRC-152 Multiband Handheld Radio is a portable, compact, tactical software-defined combat-net radio manufactured by Harris Corporation (Fig. 19). It is compliant without waivers to the JTRS. It has received NSA certification for the transmission of the top-secret data. The AN/PRC-152 radio began production in 2005. Since then, over 100,000 have been provided to the US military.

Ukraine, as part of the Western military aid, began receiving Harris radios. This included the Harris RF-310M-HH, an export version of the PRC-152 without NSA Type 1 encryption [21].

Fig. 19: AN/PRC-152 radio

Rifleman Radio. JTRS HMS (Handheld, Manpack & Small Form-Fit) radios, for individual solder, are now headed into production. The AN/PRC-154A Rifleman Radio is designed to be carried by leaders needing secret access to the platoon [22]. This is a personal radio for use directly on the battlefield. JTRS HMS AN/PRC-154 Rifleman radios weigh less than a kilogram (with a 10-hour battery and antenna) and can create self-forming, ad hoc, voice and data networks (Fig. 20). These SDRs securely transmit voice and data simultaneously using Type 2 cryptography and the new Soldier Radio Waveform. It is a joint product of Thales and General Dynamics.

The AN/PRC-154 Rifleman Radio is a handheld, intra-squad tactical radio used by the U.S. Army. General features are the following:

- Frequency range: UHF: 225-450 MHz, L-Band: 1250-1390 MHz, 1755-1850 MHz
- Transmit power: selectable, up to 5 W
- Modes: digital voice, digital data
- Waveforms: Soldier Radio Waveform (SRW)
- Encryption: NSA Type 1 algorithms (154A model), NSA Type 2 algorithms (154 model)
- GPS: Internal, optional external antenna
- Programmable channels: 50
- Weight: 1.7lbs w/ battery
- Communication range: >2km (ideal condition)

Fig. 20: A) AN/PRC-154A Rifleman Radio: three antennas according to frequency range 225-450 MHz, 1250-1390 MHz, and 1755-1850 MHz; but not just a single smart antenna; B) AN/VRC-121(V)1 VIPER Vehicle Integrated Power Enhanced Rifleman [22]

Fig. 21: Shadowcat Radio (General Dynamics) [23]

During these past 14 years, SDR technology has matured (Fig. 21), thus is thoughtful to hope for a revival of the SDR approach.

PART 2. LESSONS FROM PRACTICAL APPLICATION IN REAL CONDITIONS

What did real military events in 2022-2024 show regarding SDR?

- Radios with 64-bit encryption are easily hacked by the enemy
- Examples of remote blocking of DMR mode radios with 256-bit encryption are described
- Compatibility between different devices is key
- Low frequency tuning speed was cited as one of the main complaints about existing devices

In modern warfare, when fast-moving dispersed masses of troops are scattered over vast areas, communication is primary. You can have as many sophisticated tanks, guns, ATGMs, mega-trained special forces, and even ultra-modern mobile field bath and laundry facilities as you like, but if they all do not know where they need to be at what moment, then the enemy will safely leave the direction of the attack, hitting you in the flank.

The key requirements for a tactical military communications system are interference immunity, communication secrecy, and ensuring control of the entire "military organism" of the corresponding level - which can only be implemented in the form of a complex of various communication means.

What are the typical characteristics of modern systems? It is a software-defined radio (SDR) that covers a frequency range from 27 to 520 MHz and supports various analog and digital signals, including TETRA

- pseudo-random operating frequency - 20,000/s;
- GPS/Galileo/GLONASS positioning accuracy no more than 25/25/40 meters (latitude/longitude/altitude);
- transmission mode - time division multiplexing, text (TETRA);
- operating time of at least 6 hours from one battery;
- range up to 4 kilometers;
- reception and transmission of files, speech, text, maps, cipher codes;
- equipped with an electronic compass, an inertial motion recognition system, and an Internet of Things function, as well as Wi-Fi IEEE 802.11b/g/n and Bluetooth interfaces for remote communication with the periphery

The capabilities of the digital signal processing subsystem have been significantly expanded, allowing for a significant increase in the data transfer rate in the future and the introduction of new complex protocols for interference, reconnaissance, and crypto-protected radio communications.

The SDR platform used in the radio station provides seamless end-to-end compatibility with radio stations of different generations operating with different protocols and frequency ranges. Simultaneous support of several satellite systems allows you to determine the subscriber's coordinates and exchange navigation data in automatic or manual mode.

But the reality of using the systems in service was not so good. The speed of data transfer declared in the "advertisement" could not be realized. There are no "long-haul" connections, over 4 km, for example, without installing a chain of repeaters between subscribers. Very often, there are no frequency-hopping radio stations on armored vehicles and command and staff vehicles. There is no HF segment at all. That is, the system that was announced by the army has no similarities in the world, it is essentially unique. But it lacks a base, a powerful network of repeaters and HF stations, lacks radio stations integrated into tank intercoms.

At the same time, it is necessary to understand that a communications repeater is a very noticeable radio-emitting object, the position of which the enemy can quickly determine with high accuracy, and knocking out ground repeaters collapses the entire communications system.

The weakest link is synchronization. The noise immunity of a radio channel is determined by how synchronization is performed. If synchronization is disrupted, the communication system completely fails. Synchronization is the most vulnerable point of frequency-hopping radio systems: 1) synchronization is difficult to ensure in combat conditions and high radio interference, 2) synchronization packets become the most attractive target for electronic warfare systems and an easy target for drone attacks.

CONCLUSION

The Joint Tactical Radio System (JTRS) should play, as was planned, an important role in the U.S. Army’s proposed Future Combat System (FCS) program. Starting in 1997, JTRS was an attempt at unifying military radios by digital signal processing. It is a set of software-defined radios (SDRs). The idea was to use this system as the core element of the FCS to link all of its 18 manned and unmanned systems. This was one extremely ambitious project, and this was a basis for the strategic “Joint Vision-2010” plan oriented to the Network-Centric Warfare concept. In 2009, the FCS program was ceased.

The RAND Corporation report distilled lessons of the FCS program in detail. The FCS program was expected to interoperate with many legacy or developmental radio systems, with JTRS and WIN-T being the most well-known. The importance of developing an advanced mobile tactical Internet-like network was necessary not only for the FCS concept but also for the wider DoD community. This is the so-called MANET concept. All networks must communicate information, successfully delivering it from a source to a destination. Mobile Ad-Hoc Networks rely on wireless communication without a stable underlying wired infrastructure, unlike the Internet, which has nodes that are not mobile and rely on a relatively stable fiber optic and telephony copper wire network as the backbone. Attempting to design MANET network protocols, as the rules for optimal communication between nodes, is an immensely challenging technical problem.

Unfortunately, the FCS Network, predicated on a MANET implementation, employing ground and air systems as nodes, was thus being designed without a foundation of fundamental results. The JTRS program was projected to replace the 25 to 30 families of radio systems used in military systems. After 15 years and spending $15 billion, the JTRS program failed to deliver radios to the battlefield and was canceled in October 2011.

We are unaware of attempts to analyze radio technology, especially the MANET approach, which turned out to be the most vulnerable point in military communications, what the real events of 2022-2024 showed.

During these past 14 years, SDR technology has matured, thus is thoughtful to hope for a revival of the SDR approach.

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Manfred Sneps-Sneppe – independent researcher (email: manfreds.sneps@gmail.com)