ESSOR HDRWF – Capabilities and Perspectives of an Innovative Coalition Waveform

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***Abstract*—This paper presents the motivation and results of the European Secure SOftware defined Radio (ESSOR) programme concerning the capabilities and perspectives of the ESSOR HDRWF (High Data Rate WaveForm), an innovative coalition secure high data rate mobile ad hoc networking waveform for land military applications, brigade and below. It gives insight on ESSOR results in specifying, simulating and defining the ESSOR HDRWF. It moves from the User Requirements which drove the definition phase, resulting in a highly configurable waveform capable of adapting to different operating scenarios. It also details the main capabilities of the ESSOR HDRWF and analyzes the achievable performances, considering radio link communication aspects along with overall ad-hoc network behaviour. Impact of size and topology of the network (from scarce networks with few nodes up to dense networks with high number of nodes) is considered. In order to support proper performance assessment, this paper highlights the High Fidelity Simulation environment and methodology put in place for the definition and design phase. Integration of the ESSOR HDRWF into the more general IP based Tactical Intranet concept is also addressed and put in perspective of the associated NATO interoperability approach. In terms of innovative features, it addresses the capabilities of the ESSOR HDRWF to handle efficient synchronization in absence of common time reference (i.e: GNSS), to properly manage communication on the move and dynamic adaptation to the operational environment. In relation with the design activities, this paper presents an overview of the ESSOR Base WF approach allowing the development of portable software jointly developed by the ESSOR stakeholders, supported by the Common Criteria assurance requirements. In that perspective, the current porting activities of this shared software on the different and heterogonous National SDR Platforms are summarized. Finally this paper focuses on the different levels of system validation activities which are planned and which will culminate with interoperability tests amongst the various national SDR platforms.**

Keywords—ESSOR; SDR; HDRWF; Waveform; OCCAR; NATO; MANET; Common Criteria; Portability; SCA; IP; UHF; Base Waveform; Native Test Environment;

I. Introduction

ESSOR is a major Software Defined Radio (SDR) programme established under the umbrella of the European Defense Agency (EDA)[1], sponsored by the governments of Finland, France, Italy, Poland, Spain and Sweden. The ESSOR programme has been awarded by the Organisation Conjointe de Coopération en matière d'ARmement (OCCAR)[2] to the dedicated joint venture Alliance for ESSOR (a4ESSOR S.A.S.) in charge of managing the industrial consortium composed of the following respective National Champions (NC): Elektrobit, Indra, RADMOR, Saab AB, SELEX ES and THALES Communications & Security.

Along with the definition and implementation of the ESSOR Architecture[3] an SDR architecture extending the public part of the JTNC[4] Software Communications Architecture (SCA)[5] the main goal of the ESSOR programme is to specify, simulate and design the ESSOR HDRWF, a coalition secure networking waveform for land military applications, to develop this waveform as a shared and portable software application (the HDR Base WF), and to port and demonstrate this waveform on heterogeneous national SDR platforms (PTF).

After presenting the HDRWF concept of use (§II), this paper presents the WF main capabilities (§III), explains WF logical stack (§IV) along with information assurance aspects (§V), provides system integration views of the HDRWF (§VI), gives details on HDRWF development and validation steps (§VII), focuses on High Fidelity simulation approach (§VIII), explains the HDRWF portable software application (§IX) and system validation (§X) aspects, and finally concludes with perspectives on future steps (§XI).

II. ESSOR HDRWF CONCEPT OF USE

In a Tactical communications environment, the HDRWF is a new-generation, secure coalition network which significantly enhances the operational capabilities on the battlefield by providing high data rate services to the end users, supporting the deployment of a tactical intranet and providing transverse connectivity to coalition forces operating in the same theatre.

The HDRWF network is deployed on the battlefield at brigade level and below, works on-the-move forming a multi-hop mobile ad-hoc network, self-organizing and self-healing, and therefore increases the connectivity of mobile nodes.

The HDRWF network is a consistent Coalition Network governed by its own allocated resources (frequency plan, keys, …), allowing deployment amongst units belonging to different nations (e.g. NATO member nations), and enabling interoperability between coalition forces. It can work as a "transit network" for data communication between users of other networks or as "access network" for users communicating through a standard IPV4 wide area network.

A. Main Missions and Benefits of the HDRWF

Three missions are identified for HDRWF radio network: i) Mobile transverse network for tactical intranet: relying on mobile ad-hoc scalable network features, the system enables network centric warfare and horizontal communication schemes; ii) Extension of area networks with improved vertical (hierarchical) communication scheme for connection of headquarters (HQ). The system is used in semi-fixed configuration between established HQ and/or area network; iii) Enhanced alternative to existing data modes of legacy radios by proposing higher data rates.

HDRWF enables network centric warfare and enhance operational efficiency by i) providing transverse network used to interconnect CNR networks and/or area networks; ii) allowing communications between users, independently from hierarchical organization; iii) supporting IP inter-networking between HDRWF network and legacy/future networks with compatible security policy levels through open interfaces.

Fig. 1 provides an example of simultaneous vertical and horizontal communication schemes interconnecting forces from various nations (represented by different colours).

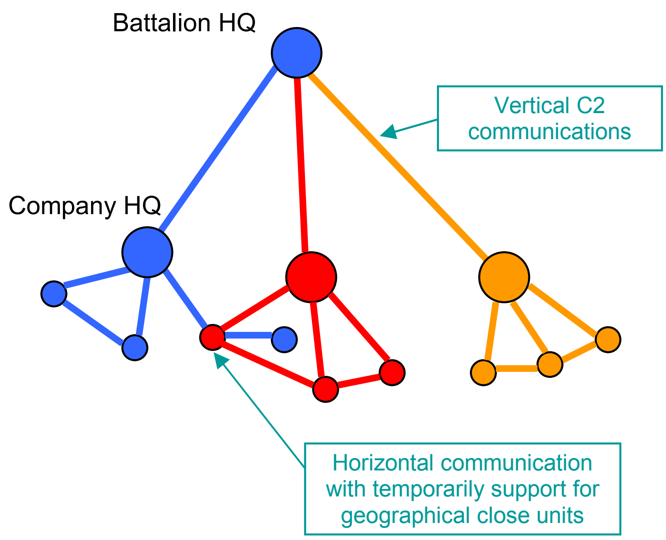

Fig. 1. Horizontal and vertical communications

B. Deployments and Use Cases of the HDRWF

Hosted on vehicular platforms, the HDRWF is used to set up a tactical communications network with up to 200 nodes, potentially belonging to a coalition deployment with several nations, achieving a coalition network by a consistent network management and operating on a pre-defined set of frequencies.

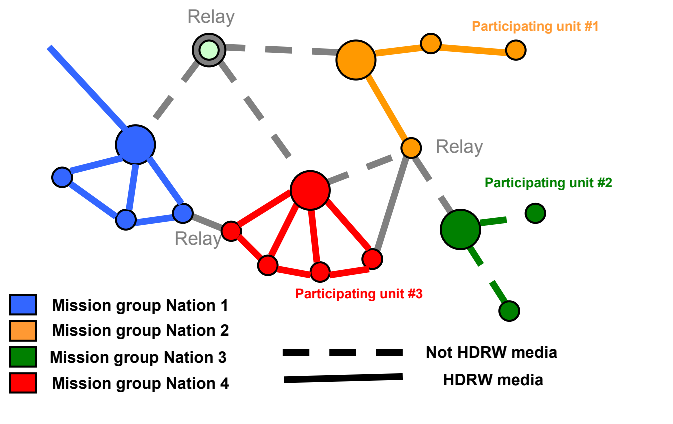

Fig. 2. Company Level scenario with mission group at platoon level

An example of interoperability between four different national groups (represented by different colours) is depicted in Fig. 2

HDRWF provides open interfaces allowing allied interoperability and possible inter-connection with other systems like naval/air components and civil organisations. Details about the inter-networking between HDRWF and a general IP-based tactical network are provided in Section VI.

In short, the networking capability of the HDRWF eases the cooperation between tactical commands and bridges the geographical and organisational boundaries. The HDRWF network can be part of a global tactical network also known as an "intranet theatre" acting as transit or access network providing secure communication capabilities in peace time, crisis time or wartime.

III. ESSOR HDRWF Main Capabilities

From the inception of the ESSOR programme, the HDRWF capabilities have been defined in order to sustain an evolutionally path. Inside the current phase of the programme:

- Threshold Capabilities refer the HDRWF features that are subject to complete detailed design, simulation, software development, porting and validation.
- Objective Capabilities refer to the HDRWF features that are addressed up to WF Architecture definition. This approach provides confidence that the architectural foundations are sound to support the full development of Objective Capabilities inside future activities. These Objective Capabilities are tagged (O) inside this paper.

A. MANET and Synchronization

The HDRWF is a multi-hop mobile ad-hoc network (MANET), supporting up to 200 nodes per network with ad-hoc mobility management of the nodes, communication on the move (up to 130 km/h) and dynamic adaptation to the environment (propagation, node density, advantaged nodes, traffic profile, …).

Each node of the network is acting as transmitter, receiver or relay and allows interconnecting distant IP networks. HDRWF is dynamically and automatically adapting to the topology. The distributed and secured synchronization mechanisms operate with and without GNSS and takes advantage when GNSS is available, even partially amongst the node of the network. After splitting, a network partition runs autonomously in stand-alone but the merging or node late entry is always possible since adequate mission parameters are shared between network's nodes. According to frequency resource available, multiple ESSOR networks can coexist on the battlefield.

B. Remote and Local Management

The HDRWF system was designed to provide local and remote management capabilities via dedicated interfaces.

Local Management interface, with the use of Human Machine Interface (HMI) of each node, provides administration functions to a local operator, such as loading of mission parameters, supervision and control of node behaviour, radio silence (O), group joining/leaving, power on/off, display of information, different notification reception e.g. faults reports and retrieval of collected logs.

Remote management interface with Network Management System (NMS) provides remote administration functions similar to those described for local operators and allows flexible integration of the ESSOR HDRWF NMS into various existing national network management infrastructures. Additionally NMS using SNMPv3 [6] is capable to perform Over the Air (OTA) network management on the information defined in Management Information Base (MIB).

C. IP Based Services

Based on IPv4 technologies, ESSOR HDRWF supports simultaneously unicast, optimized multicast and broadcast communications for IP-voice, data (Blue force tracking, FTP), and video traffic with different Quality of Services (QoS). Integration of IPv6, header compression, QoS-based routing and time critical transmission are foreseen for future steps (O).

D. Voice Services

The HDRWF voice services include VoIP and embedded Combat Net Radio (CNR) voice Push To Talk (PTT) (O), that are handled though the means of traffic shaping and priority queuing, giving voice (and other low latency) traffic preferential treatment over other services.

In order to reach the high set goals for end-to-end latency of VoIP[7] in a multi-hop environment, several QoS mechanisms are involved to achieve a minimal per-hop delay: No fragmentation and low-latency queuing of the voice packets; and for the future PTT voice capability (O), dedicated allocated transmission resources.

E. Spectrum and Signal in Space

HDRWF Signal in Space (SiS) is designed for operating on UHF frequency band (225-400 MHz) and exhibits 1,25 MHz channel bandwidth; presenting a good compromise between waveform performances and spectrum allocation for a wide range of missions and locations.

SiS utilizes several different modulation schemes in order to maximize data throughput and/or link distance

SiS supports three different data rates (~1 Mbps, ~ 512 and ~ 256 kbps) at radio link which are dynamically (automatically) selected according to channel conditions and/or communication capability needs, operates with TRANSEC based frequency-hopping as Anti-Jamming (AJ) and frequency diversity technique, and uses advanced solutions to secure communication, like interference cancellation at receiver side (for improved AJ) and self-interference avoidance in the presence of high-altitude nodes.

SiS also provides automatic and flexible frequency allocation within a pre-defined set of frequencies with automatic establishment of parallel communication on different frequency channels when adequate.

SiS design is modular / parameterized and characterized in front of several fading channels and jamming conditions. In particular, SiS has been assessed for potential use for ground-air-air communications with slow moving platforms and a differential speed of 400 km/h is achieved without degradation of performance.

IV. ESSOR HDR WF Logical Stack

Fig. 3 describes HDRWF logical stack, organized around: Physical (PHY), Medium Access Control (MAC), Link Layer Control (LLC), Networking (NET), and Management (MGT) layers. This modular architecture enables incremental development in front of future capabilities.

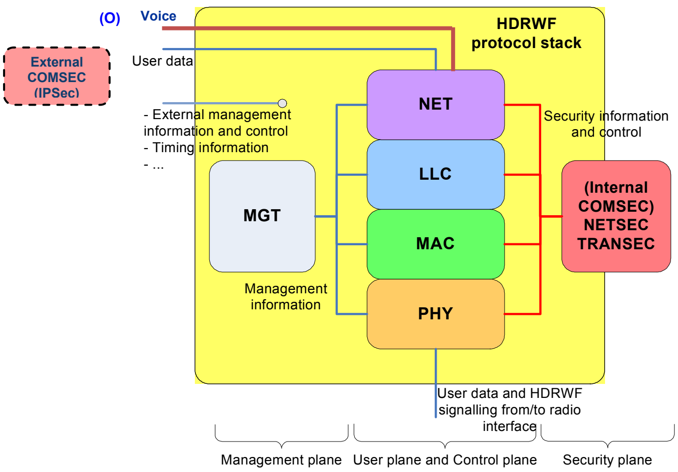

Fig. 3. HDRWF Logical Stack

A. PHY Layer

PHY layer provides the means of transmitting bit streams (user data and signalling data) over the radio link. The bit streams are mapped to symbols (modulation) and converted to a physical signal that is transmitted over the radio link. The PHY layer implements the following functionalities: transmission and reception of data, synchronization, dwell management, TRANSEC protection and transceiver.

B. MAC Layer

MAC layer provides a synchronized TDMA scheme allowing up to 200 nodes to dynamically share the transmission medium with multiple physical channels.

MAC is managing synchronization according to time reference locally available at node level (GNSS), or exchanged through the network. The nodes can be synchronized (protocol secured with NETSEC protection) without any specific node configuration, even if their respective reference time sources are different. For network where mixed node configurations with / without GNSS are deployed, MAC synchronisation algorithms allow all nodes to synchronize on the reduced set of node(s) with GNSS and therefore apply the GNSS time as their own system time. Therefore, according to table II in chapter VIII.E, it allows to pass from performances case II to case I for network initialisation duration.

MAC access scheme allows temporal slot and frequencies reuse from distant nodes thanks to a dynamic neighbourhood discovery up to 2 hops. Concerning data rate and power adaptations, the MAC layer adjusts the proper data rate (~ 256, ~ 512 or ~ 1024 Kbps) for each radio link and the transmission power according to the Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR) measured by the PHY layer at receiver side.

MAC also deals with the traffic itself by managing the radio resource allocations according to the node traffic bandwidth requests and priority of packets received from the LLC layer.

As a specific feature, MAC is also able to manage PDN (Potential Disruptive Node) like high elevation nodes (helicopter, node on top of the hill,…). When MAC detects the PDN, it then especially cancels some links between PDN and other nodes, on one hand to reduce the potential network instability and bottleneck effect on the PDN, and on other hand to optimize temporal slot and frequencies reuse: without such detection and treatment, some nodes may see “through the PDN (potentially moving)” other nodes at 2 hops and therefore cancel from using same slot and frequency whereas they have absolutely no way to interfere.

In a nutshell, the HDRWF is dynamically able to quickly adapt to the most of operational events occurring on the battlefield in order to preserve proper allocation of radio resources amongst the nodes.

C. LLC Layer

The main features of the LLC layer are traffic shaping by the means of Segmentation and Reassembly (SAR) and management of priority queues for different IP traffic according to its DSCP[8] (Differential Services Coding Point) value, giving preferential treatment for low latency traffic and high priority services. LLC also supports high reliability traffic by a tailored Automatic Repeat Request (ARQ) mechanism (hop by hop).

D. NET Layer

The NET layer receives IP packets from the upper layer and adapts them for the dispatching in the HDRWF Network. Destination IP address of the IP data are mapped to the MAC HDRWF address and some information from IP header (e.g.: Addresses, DSCP, etc.) are used for flow classification.

Route discovery and maintenance in the internal addressing plan is performed using a customized version of OLSR (*Optimized Link State Routing Protocol*) [9] which is a proactive link state protocol for mobile ad-hoc network. Routing information exchanged is minimized using MAC services for the update of 1-hop and 2-hop topology while using standard OLSR mechanism for dissemination inside the overall network, broadcasting Topology Control Messages (TC) through a set of MPR nodes (*Multi-Point Relayer*).

The algorithm defined for multicast/broadcast flows routing is based on the SMF[10] protocol (*Simplified Multicast Forwarding*). The customized algorithm, called *Pruned SMF*, avoids the forwarding of multicast packets towards some parts of the network where there are no destinations for a group, reducing the transmissions number of multicast compared to the broadcast.

E. MGT Layer

The MGT Layer controls of entire the HDRWF System Node state machine (including remote/local deactivation and re-initialization of the node) and realizes all functionalities available via local and remote management interfaces. It is also responsible for parameters (as e.g. routing table) and security material (as e.g. keys, certificates) management in entire HDRWF stack.

V. ESSOR HDRWF Information Assurance

The Information Assurance (IA) requirements on a wideband networking waveform for coalition operations are by necessity very stringent. In order to ascertain these requirements, the HDRWF has been designed and developed in accordance with the Common Criteria methodology (ISO/IEC 15408) [12].

The main IA objectives for the HDRWF are to provide Confidentiality, Integrity, Availability and Accountability to the network, the users and their assets; withstanding and mitigating all the potential threats in the tactical operational environment. This is achieved by the means of embedded communication security (COMSEC), network security (NETSEC) and transmission security (TRANSEC).

The HDRWF can operate in a red/black separated environment by the use of the internal COMSEC mechanisms, but it is also compatible with the use of external COMSEC (IPSEC)[13], in order to support a black radio paradigm.

The HDRWF design is compatible with the Crypto Equipment Application (CEA) approach to be implemented by the hosting Radio Platforms.

The HDRWF system supports embedded Over the Air Rekeying/Distribution/Zeroisation (OTAR/D/Z) mechanisms, considering that the key materials are distributed from the Security Management Center (SMC).

VI. Integration of the ESSOR HDRWF in a General IP Based Tactical Intranet

The HDRWF network has been designed with a great focus on transit network capability and internetworking with other external IP networks. An innovative idea based on bi-directional interactions between PTF IP stack and HDRWF has been introduced. External network reachability announcements generation and processing are managed completely inside the HDRWF. This is done by interactions between PTF IP stack routing information and HDRWF NET layer. In facts, bi-directional exchange of information is possible in such a way:

- Platform IP stack routing table is read by the HDRWF. Such information is used to generate internal HDRWF announcements;
- Aggregated information from HDRWF is used to update Platform IP stack routing table.

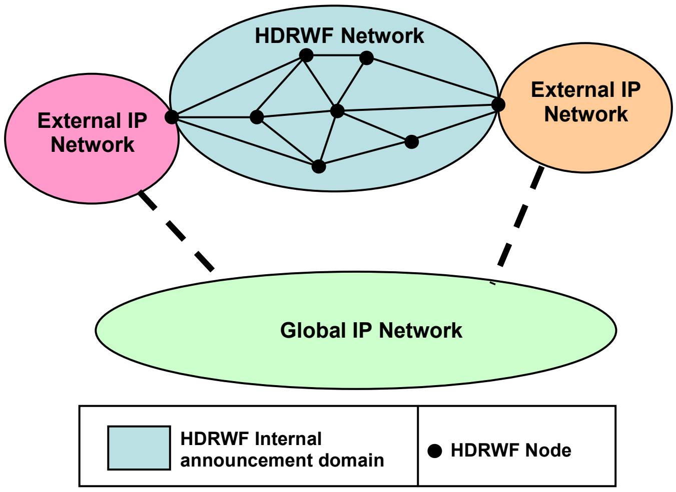

Fig. 4. HDRWF Internetworking principle

Using such approach depicted into Fig.4, announcements are generated internally to the HDRWF exploiting the information present inside the routing table of the PTF IP layer and read by the HDRWF at runtime. Such announcements are processed totally inside the HDRWF. Internetworking information is then updated inside the PTF IP layer routing table consequently through an interface between the IP layer and WF layer, used to write/read IP routing table.

Moreover it is possible to tune, internally to the WF, the rate used for generating and transmitting announcements, in order to customize and control the overall amount of internal signalling traffic that carries internetworking information and that is injected into the WF itself.

Internetworking management can be also static, i.e. pre-configured routing information is stored at mission setup time. In addition, management of multiple gateway nodes is provided in order to reduce and distribute traffic to/from destinations external to the HDRWF network.

External routing announcements and PTF routing table are under the complete control and responsibility of PTF IP Service. Once WF updates IP Service routing table, it's up to routing daemon running on IP Service to perform the duty of executing the flooding of such information to external routers; this allow for a effective decoupling between WF and PTF.

VII. HDRWF Development and Validation Steps

The HDRWF development and validation steps have been organized in order to give assurance on the associated waveform performances, to support joint development of common software (the HDR Base WF) amongst the ESSOR Nations, and to give confidence on the porting of the HDR Base WF software on the various and heterogeneous ESSOR National platforms (PTF). These development and validation steps are summarized into TABLE I.

TABLE I. HDRWF DEVELOPMENT AND VALIDATION STEPS

HDRWF Development Steps	**HDRWF Validation Steps**
HDRWF System Design	High Fidelity (HiFi) Simulations
HDR Base WF Software Development	Native Test Environment (NTE)
HDRWF ported on National SDR PTF	National Test Bed (*)
Interoperability Labs Tests	Multinational Test Bed (MTB)

- (*) National Test Bed is duplicated / extended from the MTB

VIII. ESSOR HIGH FIDELITY SIMULATION

A. System Design and Performance Trade-Off

During the System Design phase, the HDRWF achievable performances have been assessed through a progressive refinement of the technical choices based on timely decided trade-offs supported by High Fidelity (Hi-Fi) simulations encompassing a large number of complex scenarios including large number of nodes, various propagation conditions (AWGN, fast and slow fading, multi-path, jamming,…), various node density, node mobility, operations with / without GNSS, different traffic profiles (IP Unicast, Multicast, Broadcast, Situation Awareness, VoIP, …).

B. Simulation Enviroment and Methodology

The HDRWF system is described by a requirement data base composed by the chain of requirements generated from the Statement of Work followed by the system level requirements and the detailed layers requirements. Each system requirements is associated to one or more layer requirement that describes more in detail the involved functionality.

The methodology approach for the definition of the simulation scenarios and the validation of the requirements starts from single layer (PHY, MAC, LLC and NET) testing and continues with the aggregation of the protocol layers.

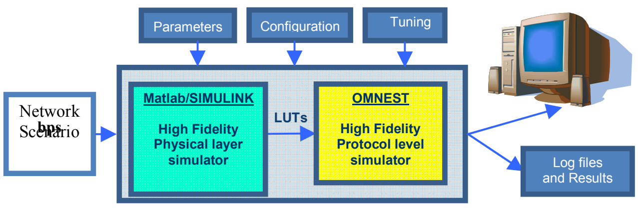

Fig. 5. HDRWF High Fidelity Simulations

As shown in Fig. 5, the Hi-Fi Simulator is composed by two sub simulators: the Hi-Fi PHY Layer Simulator and the Hi-Fi Protocol level Simulator. Both sub-simulators can run independently from each other. They can be seen as a modular system which produces reliable and accurate results.

The Hi-Fi physical layer simulator has been implemented in MATLAB/Simulink[14] environment, realizing a floating point model used for the generation of test vectors for the development and validation of the PHY layer. PHY simulation results are also collected in look-up-tables, used as input for the protocol level simulator.

The Hi-Fi protocol level simulator has been developed in a simulation environment based on OMNEST [15]. The used tool permits to model a complete network and to monitor/measure its local and global performance under different conditions. An implementation of HDRWF protocol layers, aligned with layers specifications, is integrated inside this structure and it represents the protocol stack of each simulated node.

The simulation results have been used for analysing the layers behaviour, providing a fast-feedback to the specification stage. Scenarios run in the integrated Hi-Fi protocol level simulator validate the system requirements. They are defined for providing more congruent and reliable feedback to specification, demonstrating overall system behaviour in a set of WF-level scenarios focusing on the performance aspects.

C. PHY Hi-Fi Simulation Extract

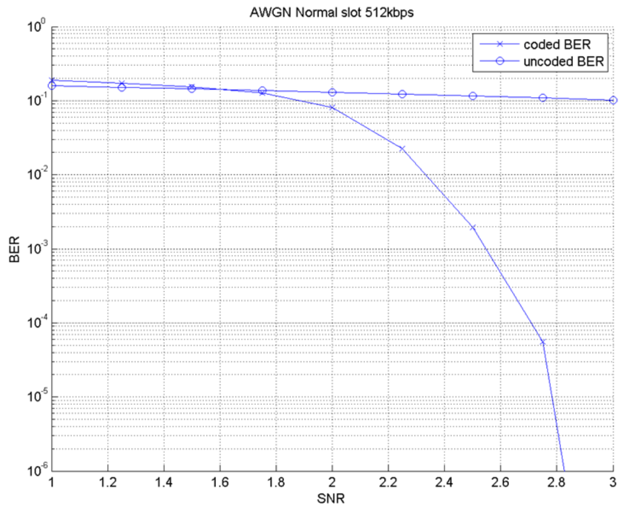

Fig. 6. HDRWF Physical Layer Performances

Fig. 6 gives an example of PHY layer simulation results for the data rate 512kbps with AWGN channel. This simulation scenario is run with all the receiver estimations (time/frequency/channel/SINR) and interference cancellation enabled. Additionally, certain RF/transceiver impairments are included (e.g. PA model, IQ imbalance and phase noise).

In this figure, the performance in terms of bit error rate (BER) vs. signal to noise ratio (SNR [dB]) is shown. Both the uncoded and coded BER are shown. While this kind of simulation results can be used to assess PHY layer performance, they also give indication about the expected performance degradation due to non-idealities (such as receiver estimations and RF/transceiver impairments) when compared to the ideal case.

D. Protocol Layer Hi-Fi Simulator Extract

The scenario example presented into Fig. 7 includes 200 nodes in a Suburban environment: 160 static nodes arranged in a grid (2km of distance between each couple of nodes) plus 40 mobile nodes with a speed of 12 meters per second. Such a scenario, with a regular grid topology, is very useful in order to achieve a better characterization of the Network behaviour and performance; in particular, the large group crossing the static grid strongly stresses the system in terms of network reconfiguration and resource allocation capabilities, creating a "worst case" simulation, if compared with operative scenarios.

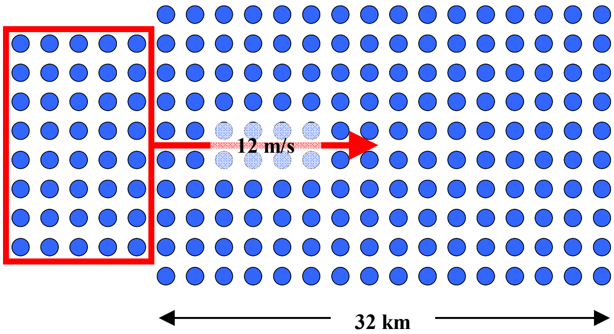

Fig. 7. Topology of the scenario

Mobile nodes cross the static grid, thus creating large modifications in the network topology. During the simulation, each node sends full broadcast situation awareness messages, consisting in one 38 Bytes long packet sent every 15 second.

Network Capacity graphic, depicted in Fig. 8, (x axis - seconds of the simulation, y axis - overall network capacity in bps) shows that network initialization is achieved in around 60 seconds, with the overall network capacity reaching 9 Mbps (for an average node capacity of 45 kbps). Network capacity progressively lowers as the mobile nodes cross the fixed grid because of the network density increase; from 550 seconds to the end network capacity oscillates around the value of 7 (for an average node capacity of 35 kbps).

Network availability results are also very promising, with a packet delivery ratio reaching 98.38%.

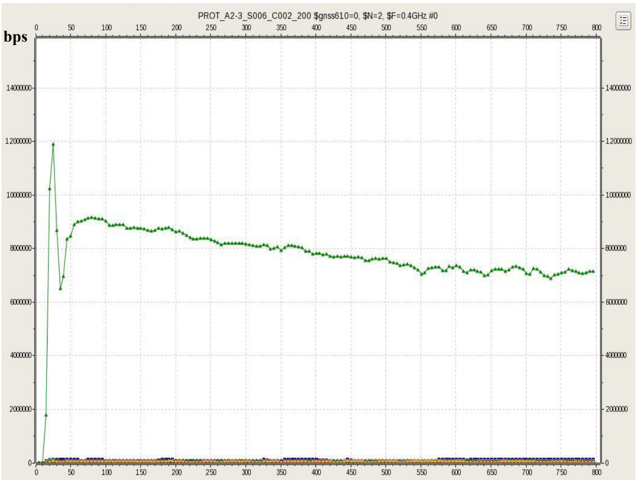

Fig. 8. Network Capacity graphic

E. Performances Extract

TABLE II. provides HDRWF network initialization duration. These Hi-Fi simulation results show fast network initialization and robust maintenance, even under adverse conditions: these figures are given for a final network connectivity reached at 95%, according to the number of nodes composing the network, the availability of the GNSS time reference in static or nominal (i.e: 20% of mobile nodes) cases. The nominal case for 200 nodes without GNSS is given for a mix of 10% nodes with GNSS and 90% nodes without GNSS.

TABLE II. NETWORK INITIALIZATION DURATION

Configuration	Nb of Nodes	Static	Nominal
(Case I) All nodes with GNSS	5	< 15 s	< 30 s
	20	< 40 s	< 1 min
	100	< 2 min	< 4 min
	200	< 3 min	< 6 min
(Case II) All nodes without GNSS	5	< 30 s	< 1 min
	20	< 2 min	< 2 min 30 s
	100	< 5 min 30 s	< 8 min 30 s
	200	< 7min 30 s	< 13 min

IX. ESSOR HDR WF PORTABLE SOFTWARE APPLICATION

A. The ESSOR HDR Base WF

The HDR Base WF represents the common portable software jointly developed by the ESSOR National Champions in order to be ported onto the different and heterogeneous ESSOR National SDR platforms (PTF).

In order to achieve this goal, the ESSOR Base WF Methodology for portability has been elaborated. The HDR Base WF software development is supported by the Common Criteria assurance requirements and the ESSOR Architecture API, and this common software is validated on the Native Test Environment (NTE) to de-risk the national porting phase.

In order to define the HDR Base WF, the HDRWF system functionalities are partitioned between:

- the HDRWF Layer Application (scope of the Base WF), including the stable functional software subject to portability,
- the WF Functional Support, part of the SDR PTF implementing the selected features of the ESSOR Architecture, with proper selection of the Radio Devices (RD), Radio Services (RS) and Radio Security Services (RSS) APIs.

The ESSOR Base WF Methodology for portability separates the stable functional software (the Golden Source) from the platform-dependent software (the Container), covers the complete Base WF development cycle (System Design, Software Design, Software Coding and Native Verification), and promotes coding rules derived among others from "Joint Strike Fighter Air Vehicle C++ Coding Standards"[11].

In order to support portability amongst heterogeneous architectures, the proper software modularity shall be identified. In front of that goal, the HDR Base WF is split into several Base Software Items (BSI) for which the selected language (C++, C, VHDL) is depending of the targeted Processing Element (PE) (GPP, DSP, FPGA).

The Target Components running on the Processing Elements of the National SDR PTFs aggregate together the "Ported Golden Source" (which can use specific libraries or accelerators if needed) and the Containers which include the code specific to each Target Platform (Operating Environment (OE), connectivity, RTOS, RD, RS, RSS, …).

B. Characteristics of the HDR Base WF

The PHY layer is developed in order to be implemented on PTFs embedding DSP and FPGA: the mapping is flexible according to the targeted PE as shown in TABLE III.

TABLE III. HDR BASE WF PHY LAYER DECOMPOSITION

PHY Layer BSIs	DSP only BSIs	FPGA only BSIs	Dual BSIs (FPGA & DSP)
16 BSI to port	4	2	10

The Protocol layers (MAC, LLC, NET and MGT) are decomposed into 17 BSIs for implementation on multiple GPP. The Golden Source code is ported using Containers dedicated to the targeted PE as shown in TABLE IV.

Concerning the Golden Source / Container decomposition approach, it could be noted that Containers are not entirely hand written and are taking benefit of usage of automated code generation tools.

TABLE IV. HDR BASE WF PROTOCOL LAYERS DECOMPOSITION

PROT Layers	Number of BSIs	Golden Source size (in SLoC (*))	Containers expected size (in SLoC (*))
MAC, LLC, NET MGT	17	230 K	140 K

(*) SLoC: Source Line of Code

C. Native Test Enviroment Simulation Activity

The Native Test Environment (NTE) is a generic functional test framework designed for all steps related to integration and validation processes of the HDR Base WF and also other waveforms compliant with the ESSOR Architecture. NTE allows: i) to create, execute and monitor test cases; ii) to record the simulation scenarios and allow replication of them.

NTE emulates the SDR platform middleware and connectivity (i.e. CORBA [16] from OMG [17] and M-HAL [18]), and includes the SCA paradigm and the ESSOR Architecture interfaces, for waveform access to platform resources (like Core Framework, Radio Devices and Radio Services). It has the capability to simulate and interconnect several SDR nodes via simulated radio channels, what allow to perform all validation and integration activities for the entire ESSOR HDR Base WF software (physical and protocol layers), in compliance with the ESSOR Base WF Methodology for Portability.

NTE is composed of protocol native test environment (for protocol layers) and physical native test environment (for PHY layer) which are interconnected together to perform system level verifications of integrated HDR Base WF stack.

D. Porting on Heterogenous SDR Platforms

The HDR Base WF is currently ported on five (5) different heterogeneous ESSOR National SDR PTFs where ESSOR Architecture has already been implemented:

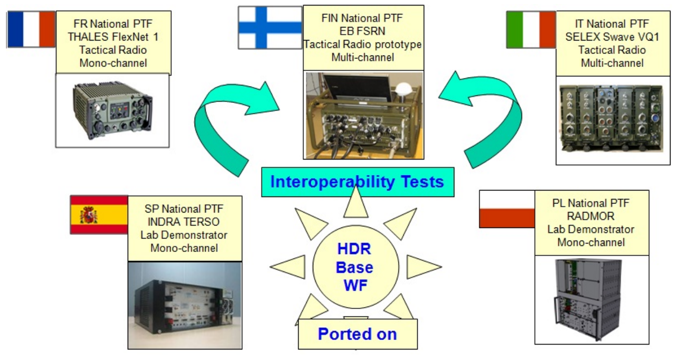

Fig. 9. Porting on Heterogeneous SDR Platforms

- The Finish National PTF is based on EB FSRN multi-channel tactical radio prototype;
- The French National PTF is based on THALES FlexNet One mono-channel tactical radio;
- The Italian National PTF is based on SELEX Swave VQ1 multi-channel tactical radio;
- The Polish National PTF is based on RADMOR mono-channel laboratory demonstrator;
- The Spanish National PTF is based on INDRA TERSO mono-channel laboratory demonstrator.

It could be noted, for budgetary constraints, Sweden has limited its national activities to the implementation of ESSOR Architecture into its own National Platform.

X. SYSTEM VALIDATION

The system test activities validate the ported HDRWF on National SDR PTFs from a system level perspective through a "black-box", where the testing environment does not know how the system under test is implemented. System tests validate different HDRWF system capabilities such as: i) WF management (monitoring and control of essential WF parameters); ii) Ad-hoc networking (time for initialization, late entry, merge/split); iii) Data transmission (unicast, multicast including dynamic group membership management, broadcast) and voice communications; iv) Security.

All system level validation activities of the HDRWF use the laboratory system test environment called Multinational Test Bed (MTB) which allows creating, executing and monitoring test cases and collecting results.

Fig. 10 presents the MTB which interconnects through an RF switch matrix up to 10 radio nodes, where each node is connected to a user LAN, in charge of transporting the user traffic. Control of all MTB components/tools is in charge of remote centralized Test Bed Controller (TBCR).

As shown into TABLE I. , the HDRWF system validation activities are decomposed in two steps: i) National Tests: these activities conclude the porting of the HDR Base WF on National SDR PTF, performed by each National Champion, in its own premises, using the replicated MTB and homogeneous national radio nodes; ii) Interoperability Tests: these activities validate communications, over the RF interface, between several different National SDR PTFs executing the HDRWF and using the replicated MTB.

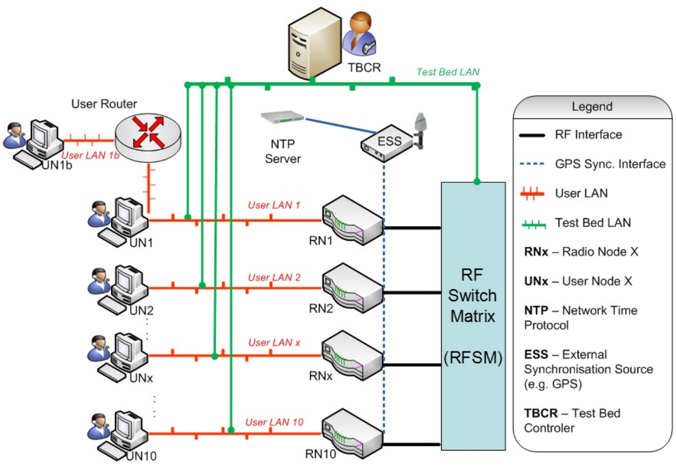

Fig. 10. High-level view of ESSOR Multinational Test Bed

XI. CONCLUSIONS AND FURTHER STEPS

This paper presents the current achievements of the ESSOR Programme in developing the HDRWF, a Secure Advance Coalition High Data Rate Waveform for mobile ad-hoc networking in UHF bandwidth. This paper provides an overview of the capabilities and performance of the waveform. The benefits for applying the ESSOR Architecture and the ESSOR Base WF Methodology for Portability are presented.

The ESSOR Programme is a successful example of joint development between different Nations and Industries in a high cooperative manner for coalition purposes. The HDRWF is aimed at becoming operational and the ESSOR Participating States intend to have the HDRWF adopted in the Coalition Wideband Networking Waveform (COALWNW) programme and as a standard for the European Community and NATO.

In parallel of these developments, future phase of the ESSOR Programme is being initiated and is addressing for the ESSOR products (ESSOR Architecture, ESSOR HDRWF): i) standardization and certification; ii) technical enhancements; iii) support to operational deployment.

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