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TECHNICAL REPORT

Autonomic network engineering for the self-managing Future Internet (AFI); An Instantiation and Implementation of the Generic Autonomic Network Architecture (GANA) Model onto Heterogeneous Wireless Access Technologies using Cognitive Algorithms

Reference

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Keywords

autonomic networking, cognition, cognitive, control, radio, self-management

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Core Network and Interoperability Testing (INT).

Modal verbs terminology

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1 Scope

The present document provides a mapping of architectural components for autonomic network management & control developed/implemented in the European Commission (EC) funded WiSHFUL Project to the ETSI TC INT AFI Generic Autonomic Networking Architecture (GANA) model - an architectural reference model for autonomic networking, cognitive networking and self-management. The mapping pertains to architectural components for autonomic decision-making and associated control-loops in wireless network architectures and their associated management and control architectures.

The objective is to illustrate how the GANA can be implemented using the components developed in the WiSHFUL and ORCA Projects. To show the extent to which the WiSHFUL architecture augmented with some virtualization and hardware acceleration techniques, developed in the ORCA project, implements the GANA model, in order to guide the industry (implementers of autonomics components for autonomic networks and their associated autonomic management & control architectures) on how to leverage this work in their efforts on GANA implementations.

The mapping of the components to the GANA model concepts serves to illustrate how to implement the key abstraction levels for autonomics (self-management functionality) in the GANA model for the targeted wireless networks context, taking into consideration the work done in ETSI TR 103 495 [i.7].

The other objective is to also illustrate the value of joint autonomic management and control of heterogeneous wireless access technologies in such a GANA implementation context, with illustration on where Cognitive algorithms for autonomics (such as Machine Learning and other AI algorithms) can be applied in joint autonomic management & control of heterogeneous wireless access networks.

The present document answers the question of how to implement the ETSI GANA model using WiSHFUL architecture and ORCA concepts.

NOTE: Trademarks in the present document that are associated with the environments considered by WiSHFUL and ORCA projects in their implementation and prototyping of components are only mentioned as Citation of the environments on which components were implemented by the the two projects. The purpose of the present document is to illustrate to the industry how such WiSHFUL and ORCA components can be used to implement the ETSI GANA components in such environments considered by the projects, while making it clear that other environments not considered by the two projects can also be considered by the industry in implementing GANA components, as the present document does not serve to endorse or limit environments in which the GANA components can be implemented.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Joao F. Santos, Jonathan van de Belt, Wei Liu, Vincent Kotzsch, Gerhard Fettweis, Ivan Seskar, Sofie Pollin, Ingrid Moerman, Luiz A. DaSilva and Johann Marquez-Barja: "Orchestrating next-generation services through end-to-end network slicing", ORCA white paper.

NOTE: Available at https://orca-project.eu/wp-content/uploads/sites/4/2018/10/orchestrating_e2e_network_slices_Final.pdf.

[i.2] ORCA Deliverable 4.3: "Enhanced operational SDR platforms with end-to-end capabilities".

NOTE: Available at https://orca-project.eu/wp-content/uploads/sites/4/2019/02/ORCA_D4.3_final.pdf.

[i.3] WiSHFUL Project Deliverable D3.2: "First operational radio control software platform".

[i.4] WiSHFUL Project Deliverable D3.4: "Second operational radio control software platform".

[i.5] WiSHFUL Project Deliverable D4.2: "First operational network control software platform".

[i.6] WiSHFUL Project Deliverable D4.4: "Second operational network control software platform".

[i.7] ETSI TR 103 495: "Network Technologies (NTECH); Autonomic network engineering for the self-managing Future Internet (AFI); Autonomicity and Self-Management in Wireless Ad-hoc/Mesh Networks: Autonomicity-enabled Ad-hoc and Mesh Network Architectures".

[i.8] Tayeb Ben Meriem, Ranganai Chaparadza, Benoît Radier, Said Soulhi, José-Antonio Lozano-López, Arun Prakash, ETSI White Paper No. 16: "GANA - Generic Autonomic Networking Architecture - Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services", First edition, October 2016
ISBN No. 979-10-92620-10-8.

[i.9] ETSI TS 103 195-2 (V1.1.1) (2018-05): "Autonomic network engineering for the self-managing Future Internet (AFI); Generic Autonomic Network Architecture; Part 2: An Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management".

[i.10] ETSI TR 103 473 (V1.1.2) (2018-12): "Evolution of management towards Autonomic Future Internet (AFI); Autonomicity and Self-Management in the Broadband Forum (BBF) Architectures".

[i.11] ETSI TR 103 404: "Network Technologies (NTECH); Autonomic network engineering for the self-managing Future Internet (AFI); Autonomicity and Self-Management in the Backhaul and Core network parts of the 3GPP Architecture".

[i.12] IEEE 802.11™-2016: "IEEE Standard for Information technology--Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.13] IEEE 802.15.4™: "IEEE Standard for Low-Rate Wireless Networks".

[i.14] White Paper No.2 of the ETSI 5G: "PoC: ONAP Mappings to the ETSI GANA Model; Using ONAP Components to Implement GANA Knowledge Planes and Advancing ONAP for Implementing ETSI GANA Standard's Requirements and C-SON: ONAP Architecture".

NOTE Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.15] ETSI GS AFI 002: "Autonomic network engineering for the self-managing Future Internet (AFI); Generic Autonomic Network Architecture (An architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management)".

[i.16] ETSI INT PoC: "5G Network Slices Creation, Autonomic Management & E2E Orchestration, with Closed-Loop (Autonomic) Service Assurance for the Slices: IoT (Smart Insurance) Use Case".

NOTE Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.17] Advanced Python Scheduler.

NOTE Available at http://apscheduler.readthedocs.io/en/latest/.

[i.18] ETSI TS 103 194: "Network Technologies (NTECH); Autonomic network engineering for the self-managing Future Internet (AFI); Scenarios, Use Cases and Requirements for Autonomic/Self-Managing Future Internet".

[i.19] WiSHFUL UPI reference specification for management (M), Network (N), Radio (R) interfaces as well as network helpers.

NOTE Available at https://wishful-project.github.io/wishful_upis/index.html.

[i.20] Report on Specifications of Integration APIs for the ETSI GANA Knowledge Plane Platform with Other Types of Management & Control Systems, and with Info/Data/Event Sources in general.

NOTE Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.21] Dunkels A., Gronvall B., Voigt T.: "Contiki a Lightweight and Flexible Operating System for Tiny Networked Sensors". In Proceedings of the 9th Annual IEEE™ International Conference on Local Computer Networks, Washington, DC, USA, October 2004; pp. 455-462.

[i.22] E. Blossom. Gnu software radio.

NOTE Available at http://gnuradio.org.

[i.23] Ruckebusch P., De Poorter E., Fortuna C., and Moerman I. (2016): "GITAR: Generic extension for Internet-of-Things ARchitectures enabling dynamic updates of network and application modules". Ad Hoc Networks, Volume 36, Part 1, January 2016, Pages 127-151.

[i.24] WiSHFUL Project Deliverable D2.1: "High level requirements for testbeds and software platforms".

[i.25] WiSHFUL Project Deliverable D2.2: "Specification of first showcases".

[i.26] WiSHFUL UPI definition.

NOTE: Available at https://wishful-project.github.io/wishful_upis/wishful_upis.html.

[i.27] ZeroMQ Realtime Exchange Protocol.

NOTE Available at http://rfc.zeromq.org/spec:36.

[i.28] ORCA (Orchestration and Reconfiguration Control Architecture) project website.

NOTE Available at https://www.orca-project.eu.

[i.29] Tarik Kazaz, Wei Liu, Xianjun Jiao, Ingrid Moerman, Francisco Paisana, Clemens Felber, Vincent Kotzsch, Ivan Seskar, Tom Vermeulen, Sofie Pollin, Martin Danneberg and Roberto Bomfin: "Orchestration and Reconfiguration Control", EUCNC June 2017. Oulu, Finland.

[i.30] ORCA Deliverable 2.1: "Technical requirements of the ORCA test facility".

NOTE Available at https://orca-project.eu/wp-content/uploads/sites/4/2017/01/ORCA_D2.2_Final_v1.1.pdf.

[i.31] Wei Liu, Joao F. Santos, Jonathan van de Belt, Xianjun Jiao, Ingrid Moerman, Johann Marquez-Barja, Luiz DaSilva and Sofie Pollin: "Enabling Virtual Radio Functions on Software Defined Radio for Future Wireless Networks", to appear in Wireless Personal Communications.

[i.32] R. Chaparadza, et al.: "SDN Enablers in the ETSI AFI GANA Reference Model for Autonomic Management & Control (emerging standard), and Virtualisation Impact". In the proceedings of the 5th IEEE™ MENS Workshop at IEEE Globecom 2013, December, Atlanta, Georgia, USA.

[i.33] White Paper No.4 of the ETSI 5G PoC: "ETSI GANA as Multi-Layer Artificial Intelligence (AI) Framework for Implementing AI Models for Autonomic Management & Control (AMC) of Networks and Services; and Intent-Based Networking (IBN) via GANA Knowledge Planes".

NOTE Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.34] White Paper No.1: "C-SON Evolution for 5G, Hybrid SON Mappings to the ETSI GANA Model, and achieving E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices by Cross-Domain Federated GANA Knowledge Planes".

NOTE Available at https://intwiki.etsi.org/images/ETSI_GANA_in_5G_PoC_White_Paper_No_1_v1.28.pdf.

[i.35] White Paper No.3: "Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the ETSI GANA Knowledge Plane for Autonomic Service Assurance of 5G Network Slices; and Orchestrated Service Monitoring in NFV/Clouds".

NOTE Available at https://intwiki.etsi.org/images/ETSI_5G_PoC_White_Paper_No_3_2019_v1.19.pdf.

[i.36] White Paper No.5: "Artificial Intelligence (AI) in Test Systems, Testing AI Models and the ETSI GANA Model's Cognitive Decision Elements (DEs) via a Generic Test Framework for Testing ETSI GANA Multi-Layer Autonomics & their AI Algorithms for Closed-Loop Network Automation".

NOTE Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.37] White Paper No.6: "Generic Framework for Multi-Domain Federated ETSI GANA Knowledge Planes (KPs) for End-to-End Autonomic (Closed-Loop) Security Management & Control for 5G Slices, Networks/Services".

NOTE Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

Autonomic Behaviour (AB): process which understands how desired Managed Entity (ME) behaviours are learned, influenced or changed, and how, in turn, these affect other elements, groups and networks [i.18]

NOTE: In the GANA model, an autonomic behaviour is any behaviour of a DE that is observable on its interfaces. A GANA DE is also called an Autonomic Function (AF).

autonomic networking: networking paradigm that enables network devices or elements (physical or virtual) and the overall network architecture and its management and control architecture to exhibit the so-called self-managing properties, namely:

- Auto-discovery of information and entities
- Self-configuration (auto-configuration), Self-diagnosing, Self-repair (Self-healing)
- Self-optimization, and other self-* properties

NOTE 1: Autonomic Networking can also be interpreted as a discipline involving the design of systems (e.g. network nodes) that are self-managing at the individual system levels and together as a larger system that forms a communication network of systems.

NOTE 2: The term "autonomic" comes from the autonomic nervous system (a closed control loop structure), which controls many organs and muscles in the human body. Usually, humans are unaware of its workings because it functions in an involuntary, reflexive manner - for example, humans do not notice when their heart beats faster or their blood vessels change size in response to temperature, posture, food intake, stressful experiences and other changes to which human are exposed. And their autonomic nervous system is always working [i.18].

Decision Making Element (DME): functional entity designed and assigned to autonomically manage and control its assigned Managed Entities (MEs) by dynamically (re)-configuring the MEs and their configurable and controllable parameters in a closed-control loop fashion

NOTE 1: Decision Making Elements (DMEs) [i.19] referred in short as Decision Elements (DEs) fulfil the role of Autonomic Manager Elements.

NOTE 2: In GANA a DE is assigned (by design) to very specific MEs that it is designed to autonomically manage and control (ETSI GS AFI 002 [i.15] provides more details on the notion of ownership of MEs by specific DEs required in a network element architecture and the overall network architecture).

Managed Entities (MEs): physical or logical resource that can be managed by an Autonomic Manager Element (i.e. a Decision Element) in terms of its orchestration, configuration and re-configuration through parameter settings [i.18]

NOTE: MEs and their associated configurable parameters are assigned to be managed and controlled by a concrete DE such that an ME parameter is mapped to one DE. MEs can be protocols, whole protocol stacks, and mechanisms, meaning that they can be fundamental functional and manageable entities at the bottom of the management hierarchy (at the fundamental resources layer in a network element or node) such as individual protocols or stacks, OSI layer 7 or TCP/IP application layer applications and other types of resources or managed mechanisms hosted in a network element (NE) or in the network in general, whereby an ME exposes a management interface through which it can be managed. MEs can also be composite MEs such as whole NEs themselves (i.e. MEs that embed sub-MEs).

OpenWRT: According to https://openwrt.org/ OpenWRT is a Linux™ operating system for people who want to install high-performance, easily-configured, reliable and robust firmware on a home router or embed the Linux-based software in other equipment.

overlay: logical network that runs on top of another network

EXAMPLE: Peer-to-peer networks are overlay networks on the Internet. They use their own addressing system for determining how files are distributed and accessed, which provides a layer on top of the Internet's IP addressing.

self-advertising: capability of a component or system to advertise its self-model, capability description model, or some information signalling message (such as an IPv6 router advertisement message) to the network in order to enable other entities to discover it and be able to communicate with it, or to enable other entities to know whatever is being advertised

self-awareness: capability of a component or system to "know itself" and be aware of its state and its behaviours

NOTE: Knowledge about "self" is described by a "self-model".

self-configuration: capability of a component or system to configure and reconfigure itself under varying and unpredictable conditions

self-healing: capability of a component or system to detect and recover from problems (manifestations of faults, errors, failures, and other forms of degradation) and continue to function smoothly

self-monitoring: capability of a component or system to observe its internal state, for example by monitoring quality-of-service metrics such as reliability, precision, rapidity, or throughput

self-optimization: capability of a component or system to detect suboptimal behaviours and optimize itself to improve its execution

self-organizing function: function that includes processes which require minimum manual intervention

self-regulation: capability of a component or system to regulate its internal parameters so as to assure a quality-of-service metric such as reliability, precision, rapidity, or throughput

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
AB	Autonomic Behaviour
AF	Autonomic Function
AFI	Autonomic network engineering for the self-managing Future Internet
AI	Artificial Intelligence
AMC	Autonomic Management & Control
AN	Access Node
ANS	Autonomic Nervous System

API	Application Programming Interface
ARM	Advanced RISC Machine
BBF	BroadBand Forum
BSS	Business Support System
CF	Control Framework
CP	Control Program
CPU	Central Processing Unit
C-SON	Centralized Self Organizing Network
DE	Decision making Element
DeMe	Rfp_GANA-Level2&3-AccessToProtocolsAndMechanisms
DME	Decision making Element
E2E	End to End
EC	European Commission
EMS	Element Management System
FlowDesc	Flow Description
F-MBTS	Federation MBTS
FMM	Rfp_FederationMBTS- to-FederationMBTS
FOO	Rfp_ONIX-to-ONIX
FPGA	Field Programmable Gate Array
FuDe	Rfp_FunctionLevelDE-to-FunctionLevelDE
GANA	Generic Autonomic Network Architecture
GCP	Global Control Program
GITAR	Generic extension for Internet-of-Things Architectures
G-MBTS	Gouvernance MBTS
GNU radio	GNU's Not Unix™ radio
GoS	Rfp_OSS_to_Governance-MBTS
GPS	Global Positioning System
IBN	Intent Based network
INT	Core Network and Interoperability Testing
IP	Internet Protocol
IPFIX	Internet Protocol Flow Information eXport
IPv6	Internet Protocol version 6
IRIS	Implementing Radio In Software
KP	Knowledge Plane
KP DE	Knowledge Plane Decision-making Element
LAN	Local Area Network
LQI	Link Quality Indicator
LTE	Long Term Evolution
MAC	Medium Access Control
MBTS	Model Based Translation Service
MCE	Monitor and Configuration Engine
ME	Managed Entity
ME-to-DE	reference point ME to DE
MIB	Management Information Base
MIPS	Microprocessor without Interlocked Pipelined Stages
MO	Managed Object
NBI	NorthBound Interface

NOTE: See Figures 11 and 12.

NDPI	Native Device Programming Interface
NE	Network Element
NeDe	Rfp_NetworkLevelDE-to-NetworkLevelDE
NeI	Rfp_NetworkLevelDE-to-ONIX-System
NeM	Rfp_EMS_OR_NMS-to-NodeMainDE
NeMe	Rfp_NetworkLevelDE-to-NodeMainDE
NF	Network Function
NFV	Network Function Virtualisation
NIC	Network Interface Card
NMS	Network Management System
NoDe	Rfp_NodeMainDE-to-NodeMainDE
NoI	Rfp_NodeMainDE-to-ONIX-System

NTP	Network Time Protocol
ONAP	Open Networking Automation Platform
ONIX	Overlay Network for Information eXchange
OODA	Observe, Orient, Decide and Act Loop
OR	logical OR symbol
ORCA	Orchestration and Reconfiguration Control Architecture
OS	Operating System
OsDE	reference point OSS knowledge plane Decision-making Element
OsDe	Rfp_OSS-to-Network-Level-Des
OSI	Open Systems Interconnection
OsI	Rfp_OSS-to-ONIX-System (Network Governance Reference Point: OSS/BSS to ONIX) (Knowledge Plane)
OSi	Rfp_OSS-to-ONIX-System (Network Governance Reference Point: OSS/BSS to ONIX) (Knowledge Plane)
OSS	Operation Support System
PC	Personal Computer
PER	Packet Error Rate
PHY	Physical
PoC	Proof of Concept
PON	Passive Optical Network
PRR	Packet Received Rate
PTP	Precision Time Protocol
QoS	Quality of Service
RAN	Radio Access Network
RAS	Reconfigurable Antenna Systems
RAT	Radio Access Technology
RF	Radio Frequency
RISC	Reduced Instruction Set Computing
RRH	Remote Radio Head
RSSI	Received Signal Strength (power) Indication
SDN	Software Defined Networks
SDR	Software Defined Radio
SNMP	Simple Network Management Protocol
SON	Self Organizing Networks
TAISC	Time Annotated Instruction Set Computer
TB	Technical Body
TC	Technical Committee
TCP/IP	Transfer Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
UPI	Unified Programming Interface
UPI_G	Unified Programming Interface Global
UPI_HC	Unified Programming Interface Hierarchical Control
UPI_M	Unified Programming Interface Management
UPI_N	Unified Programming Interface Network
UPI_R	Unified Programming Interface Radio
USRP	Universal Software Radio Peripheral
VoIP	Voice over IP
WARP	Wireless open-Access Research Platform
WG	Working Group
WiFi™	IEEE 802.11™ family of standards
WiSHFUL	Wireless Software and Hardware platforms for Flexible and Unified radio and network controL
WLAN	Wireless Local Area Network
WMP	Wireless MAC Processor
WSN	Wireless Sensor Network
xDSL	any Digital Subscriber Line
XFSM	eXtended Finite State Machines
xPON	any PON
ZRE	ZeroMQ Realtime Exchange protocol

4 Principles for Autonomic Networking and Enablers

4.1 Overview on Autonomics Principles and Enablers, and introduction to the emerging concept of "Network compartmentation"

Autonomic networking paradigm aims at creating self-managing networks to overcome the rapidly growing complexity of current networks and future networks. The complexity aspect of particular concern is management and control of the networks and services they are required to deliver to various service consumers. Management complexity can be characterized by factors such as huge number of devices, services to be provisioned and assured, and configuration parameters of network resources that need to be configured and dynamically optimized to cope with various workloads and challenges the networks encounter daily during their operations, e.g. manifestations of faults/errors/failures/security threats and performance degradations on various network resources. The autonomic networking paradigm is the enabler for self-driving and self-aware networks and services.

Autonomic networking mimics biological autonomic systems, especially those complex life forms that are provided with an Autonomic Nervous System (ANS) that is not consciously controlled. Analogously to biological systems, current networks require a conscious control that is mimicked by a centralized network control where a central entity (the brain), receives information from the peripheral elements, knows the status of the whole system, takes decisions and finally applies actions by sending commands to peripheral actuators (muscles). Biological and networking components share such general principles. However, in many applications in wireless networks, the timing for decisions is not compatible with latencies due to the loop from the peripheral sensor to the central intelligence and back to peripheral actuators. In such a case, as discussed in clause 5.5, forms of control by delegation has to be taken into account. The ETSI GANA standard takes into consideration this issue.

Autonomic systems require specific capabilities that appear to be in common with current trends in networks, especially with wireless networks. These capabilities (functions) include:

- Autognostic capabilities (self-discovery, awareness, and analysis).
- Control capabilities on network elements and interfaces.
- Capabilities to define and verify performance and constraints.
- Capabilities to identify attacks and run defending actions.

The WiSHFUL project does not deliberately aim at creating autonomic networks because it is focused on radio and network control for experimentation in wireless networks. However, it appears that WiSHFUL naturally fulfils most of the principles indicated above and provides key enablers for autonomic networks. The ETSI GANA architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services (ETSI TS 103 195-2 [i.9]) is purposely designed for autonomic networks and is fully specified in the ETSI standard ETSI TS 103 195-2 [i.9] (while a brief introduction to the GANA model is also provided later in the present document); it defines high-level requirements and architectural components for self-management networks. Conversely, WiSHFUL architecture provides the low-level requirements for wireless autonomic networks, which also map well to the GANA framework; in fact, the project defines programmability models and control models for radio and network components.

GANA Autonomic Management and Control (AMC) software modules called Decision-making-Elements (DEs) are meant to be designed in such a way that they employ such models in driving autonomics in a Network Element/Function (NE/NF) and in the outer realm (the management and control systems realm) overlay. For more details on this subject clause 4.6 of the present document discusses the GANA abstractions levels for autonomicity (autonomic/self-management functionality) and how they complement each other.

NOTE 1: The present document aims to illustrate to autonomics implementers how to use WiSHFUL components and components from the ORCA project as well, to implement the GANA framework's multi-layer autonomics in order to realize autonomic management and control of heterogeneous wireless access technologies using cognitive algorithms.

NOTE 2: WiSHFUL provides platforms, tools and architectural elements for wireless experimentation. WiSHFUL does not take into account security, and the experimental environment is considered trusted. No detection of misbehaving nodes is implemented and autonomic capabilities of self-defence are out of scope for the WiSHFUL project.