***Report on FET consultation meeting on Communication paradigms for 2020***
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# Area: Autonomic Communication

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## Scope, Vision, Challenges

Autonomic Communication has a broad scope, addressing all facets of communication - human-to-human, human-to-cyber, business-to-business, cyber-to-cyber, etc - by empowering network elements to best fit communication intentions, to observe and to react by self-organisation to context changes without explicit user interaction.

Autonomic Communication is a paradigm in which the applications and the services are not ported onto a pre-existing network, but where the network itself grows out of the applications and the services that end users wants. It can be characterised as service-driven, situated, autonomously controlled, self-organised, distributed, technology independent and scalable.

Autonomic communication will need to study the individual network element as it is affected by and affects other elements and the often numerous groups to which it belongs as well as network in general. Autonomic Communication theoretical goals are to understand how desired element's behaviours are learned, influenced or changed, and how, in turn, these affect other elements, groups and network.

Autonomic communication will be centred around networking ***selfware*** - a novel approach to perform network control, as well as management, middle box communication, service creation and composition of network functionalities, etc. based on universal and fine-grained multiplexing of numerous policies, rules and events that is done autonomously but facilitates desired behaviour of groups of network elements. It shall facilitate in particular innovative cross-layer optimised or non-layered protocol stacking

### *Identified Research Challenges*

**1. *Telecommunication strategy towards Autonomic Communication*** is to allow new services, bottom up services, composed services, self-adaptable and self-configurable growing infrastructure, context management and data mining, synergies between peer-to-peer and context awareness, awareness of services situations enabling semantic mediation for transport peering and collaboration. Envisaged is the following logical architecture paradigm: cooperative applications on top of selfware systems.

**2.** ***Zero-effort deployment*** ("spray deployment") will need to facilitate at any scale (smart dust, PAN, Internet nodes) self-assembly of communication-computational particles; programming paradigms should focus on local, autonomic cooperation and propagation fields.

**3.** ***Programming of self-organisation***. This will include both ***architectural programmability*** enabled by extended van Neumann paradigm - with virtual layer above and *quantic* layer below to reduce the visible complexity and to add stochastic aspect and include reflection of communication knowledge, context networks, and communication applications. The main challenge is that knowledge of communication is reflected inside the network and implemented by autonomic network elements.

**4.** ***Self-Management in Autonomic Communication***, addressing consistency of coordinated distributed decisions, security boundaries, boundaries of controllability, emergent reliability, conflicts, conflict resolution through negotiation, need to analyse issues with mobile code, dynamic composition of protocols and services, export of functions to different layers, the need not only to deploy but also to discard obsolete or undesirable functions. Autonomic Communication, along with cross layer optimisation will need to consider tensions and conflicts in scenarios of mass device coordination.

**5.** ***Autonomic Communication contribution to Network Information Theory*** will address fundamental problems of multiple media, and multiple resources (not only bandwidth, but also storage, processing, power, mobility, context and their possible trade-offs) in a cross-layer optimised settings; research should be carried in the middle (overlay) between packet transport engine and applications, enabling a network to migrate from *data transport engine* to *information transport/gathering/ exchange/processing engine*.

**6.** ***Security and Protection*** in Autonomic Communication will come from the embedding of security and trust requirements into communication system's functionality (*model driven security*) and by investigating how simple security components are developing complex behaviours. These behaviours in turn will result from the process of negotiation of protection level agreements, so that Autonomic Communication will meet security at business level. Further, since autonomic nodes could self-program their networking behaviour out of the cooperative standard to gain maximum advantage against others, this will call for novel techniques for trusted software and trusted flow on untrusted hosts that cannot be based on existing security paradigms such as public key infrastructures or controversial hardware trusted computing platforms.

**7.** ***Coordination and Intelligence in Service Provisioning for Autonomic Communication*** will require research in loosely coupled distributed systems and networks, support the dynamic integration of business processes and applications, the evolution and adaptation of distributed services. This research will enable Autonomic Communication systems to support strategic and business service and trust requirements and to adapt flexibly to evolutions at the business level. The above intelligence will also facilitate the so-called cooperative networking, where network operators with different and not easily compatible business models can jointly offer networking services. Specifically for wireless networks Autonomic Communication, along with cross layer optimisation will need to consider tensions and conflicts in scenarios of mass device coordination; this can be based on genetic approaches for example.

**8**. ***Behaviour knowledge and knowledge execution in Autonomic Communication***[1] will require research in ensemble management, introspection, mediation, ontology acquisition and use, optimization, contextualisation, including identification of technologies suitable for standardisation. This research will enable Autonomic Communication systems to capture and follow the *Concept drift* over time.

**9.** ***Programming of self-organisation*** will include reflection of communication knowledge, context networks, and communication applications. The main challenge is that knowledge of communication is reflected inside the network and implemented by autonomic network elements, it will consider the structure and dynamics of metaphysical networks (e.g. trust networks) in their context as well.

## Objectives - Research Themes *(Specific research areas, disciplines involved)*

The above research challenges are clustered in the following highly inter-dependent though different in methodologies research themes:

1. **Self-ware** - the core Autonomic Communication technology.

This research will explore paradigms for *horizontal* self-organisation for coordination, control, management, security, evolvability, etc. at micro- (atomic unit of control and communication), and macro- (composed Autonomic Communication systems) levels. Resulting outcome: proof-engineered platform for Autonomic Communication systems, research multiplier.

2. **Knowledge-ware** - virtualisation of Autonomic Communication platform.

This research will aim to maintain human-friendly *look and feel* of Autonomic Communication platform to facilitate vertical self-organisation of Autonomic Communication systems, enabling natural interactions of humans with natural and cyber worlds, allowing intuitive programming of self-organisation by explicit sensing of metaphysical networks.

3. **Sensor-ware** - contextualisation of Autonomic Communication

This research will study laws of information propagation, gathering, filtering, aggregation, transcoding and mapping in Autonomic Communication systems that live in multiple and dynamic contexts, such as natural - traditional sensor networks, human - metaphysical networks, cyber - various, often virtual cyber realms with heterogeneous technologies implementing them and helping to sense in them and to program the above sensing information based on selfware.

4. **Service-ware** – business driven evolution of Autonomic Communication platform.

This research will study how strategic, market, social, and business needs impact on Autonomic Communication, and how networks and applications can support the business life cycle, enabling a service oriented, requirement and trust driven development of Autonomic Communication application driven networks.

The following disciplines will be involved in search for solutions and will be attracted by challenges of Autonomic Communication:

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[1] See *Autonomic Communication* specific background information for this topic in the Annex

Traditional communication disciplines; new network information theory; control theory, esp. chaos control, team theory, cyber physics applied to networks, highly optimised tolerance; social psychology, coordination theory, large scale systems complexity theory, group communication theory, genetic algorithms theory.

## **Future Technological Potential - Deliverables!** *(Expected impact on technology, society, applications; Examples of IPs-NoEs ~ effort)*

Based on the above research theme the following list of research efforts is proposed:

1. Self-ware effort: with multi-disciplinary impact, main technology (=investment) attractor

2. Knowledge-ware effort: with impact on network information theory, on Information Society theory

3. Sensor-ware effort: impact on both communication theory and practice, network architectures, etc.

4. Service-ware effort[2]: impact on communication practices, business models for autonomic communication, etc.

5. Cross-issues coordination effort: to keep all the efforts in synch, to assure focussed, goal-driven research.

Proposals are expected to be interdisciplinary nature Integrated Projects. As one example, a proposal can be made to provide enabling technology in terms of self-ware, self-progrmmability, self-management, trust and security allowing users to grow the networks around the services they need. As another example, one may consider an IP focussing on the contextualized and localized nature of the autonomic network in which the sensorized (terminal) nature of the network play a catalyst role.

An effective Network of Excellence (acting as a cross-issue coordination) could be built to integrate competences needed for the study of theoretical limits and potentialities of autonomic communication. This network could contribute to advances in information theory, communication, security, knowledge, ontology theory, and business models for autonomic communication networks.

[2] This effort is in close coordination with knowledge-ware, however it is a stand-alone effort here to separate fundamental research concern from that of applied research.

## Annex

Comments and background material to topic 8 '***Behaviour knowledge and knowledge execution in Autonomic Communication'*** by M. Mulvenna

In order to drive the self-adaptive capabilities of autonomic communications, there is a requirement for the network to be self-aware. Research on self-awareness in next generation networks can be driven by attempting to understand the context and behaviour of the network. To achieve this, the network must have access to various data and knowledge components, and execute on this data and knowledge to modify its parameters.

The data and knowledge sources are:

- Deriving and using first- and second-order data from the data plane of the network;
- Deriving and using network management data and knowledge from the control plane of the network;
- Deriving and using data and knowledge that comprises the knowledge plane (Clark et al, 2003) of a network.

The first two data and knowledge sources can be and are employed to varying degrees in network research today. The third area represents a significant advance in research thinking, in that it is primarily inferential and mined knowledge that is discovered by predictive analytic techniques residing on the knowledge plane. These techniques include collaborative filtering (Shardanand and Maes, 1995) and (Resnick *et al*, 1994), Bayesian networks (Heckerman *et al*, 1995), clustering (Jain and Dubes, 1988), classification (Mitchie et al, 1994), association rules (Agrawal and Srikant, 1994), sequence analysis (Büchner et al, 2000) and content filtering (Mobasher et al., 2000).

The knowledge plane must have the capacity to retain and maintain a *network memory*, comprising the data and knowledge sources indicated above. This memory will be a machine-understandable XML-based syntax, comprising different standards that maintain high semantic integrity and coherence for the data and knowledge; for example, the Predictive Modelling Mark-up Language (PMML). PMML is an XML-based standard developed by the Data Mining Group[3] with the aim of aiding model exchange between different model producers and between model producers and consumers. Most data mining vendors have their own proprietary representations for knowledge discovered using their algorithms. PMML provides the first standard representation that is adhered to by all the major data mining vendors. Being XML-based, models represented in PMML can be easily parsed, manipulated and used by automated tools. The use of PMML within the network context effectively decouples the self-adaptive engine from the producer of the knowledge that it uses.

The network memory will be maintained as a discrete ontological construct in the knowledge plane, necessitating new research in network ontologies. *This memory is, in essence, a collection of rule sets that can maintain network policies as well as behavioural descriptions and policies*. As such, it is a memory that provide context for measurement. Therefore, via introspection and mediation, the memory can self adapt to improve performance depending on the context and needs of use.

In order to execute the behavioural knowledge (network memory), a scalable high-performance engine is required. This is similar in construct to a *recommender* engine, in that it is constantly updating the network memory rule bases based upon the application of predictive algorithms on network behavioural data. A key component is the detection by this engine of network trends and subtle changes in data flows, for

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[3] www.dmg.org

example. Key research currently under way in *concept drift* will be the basis for drift detection in our autonomic network architecture (Black and Hickey, 2003).
There are key challenges in this research sub-area of autonomic communications, including the real time handling and assessment of ensembles of behavioural knowledge to improve network provision and the ability to introspectively measure the performance, accuracy and appropriateness of network performance.

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