Future Internet – Research Challenges and Opportunities

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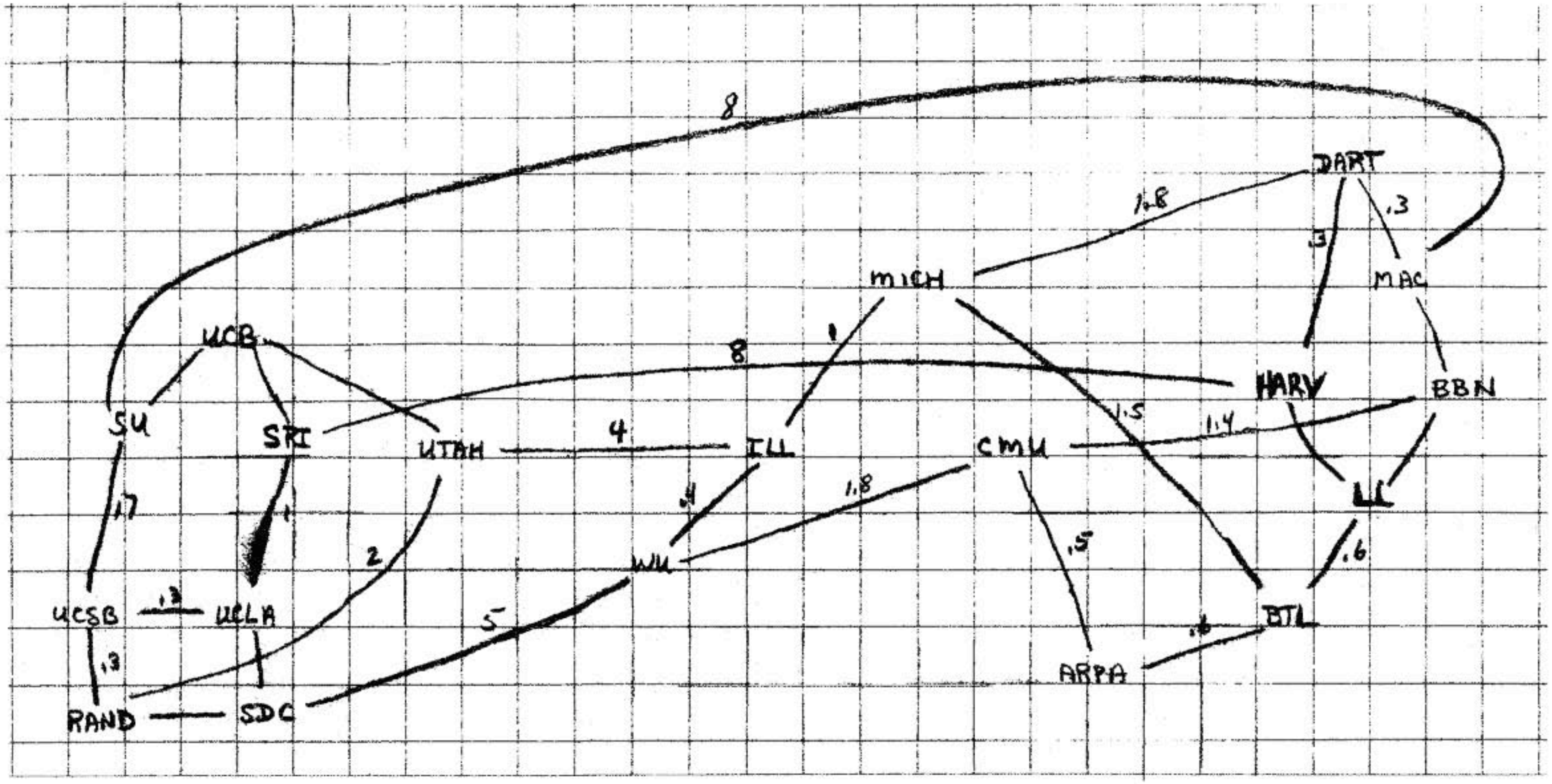
Content

- Internet Today and Drivers for change
- Future Internet Research Challenges

ARPAnet Plan – late 1960s
Rough sketch by Larry Roberts



Internet 1973-74

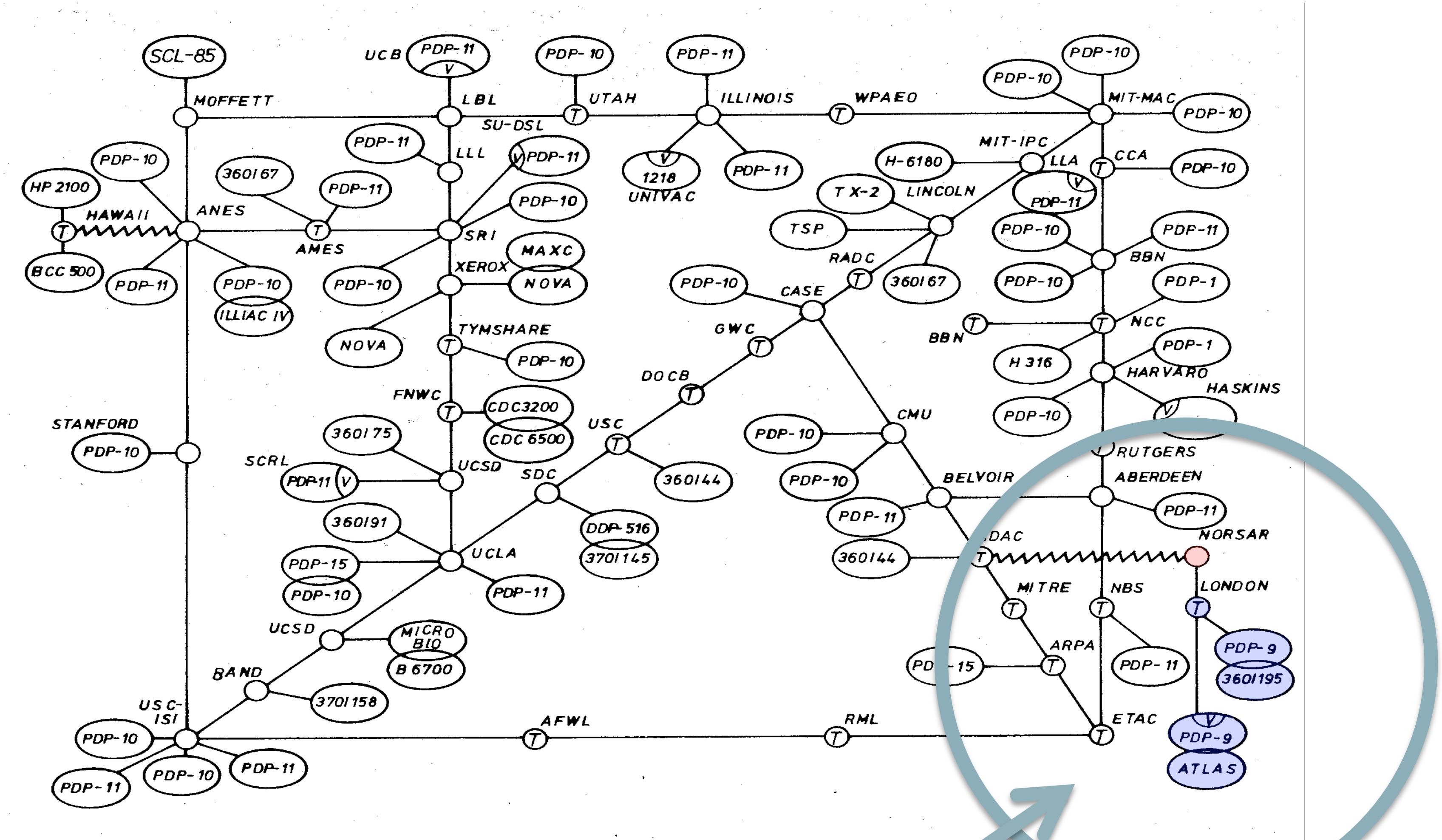
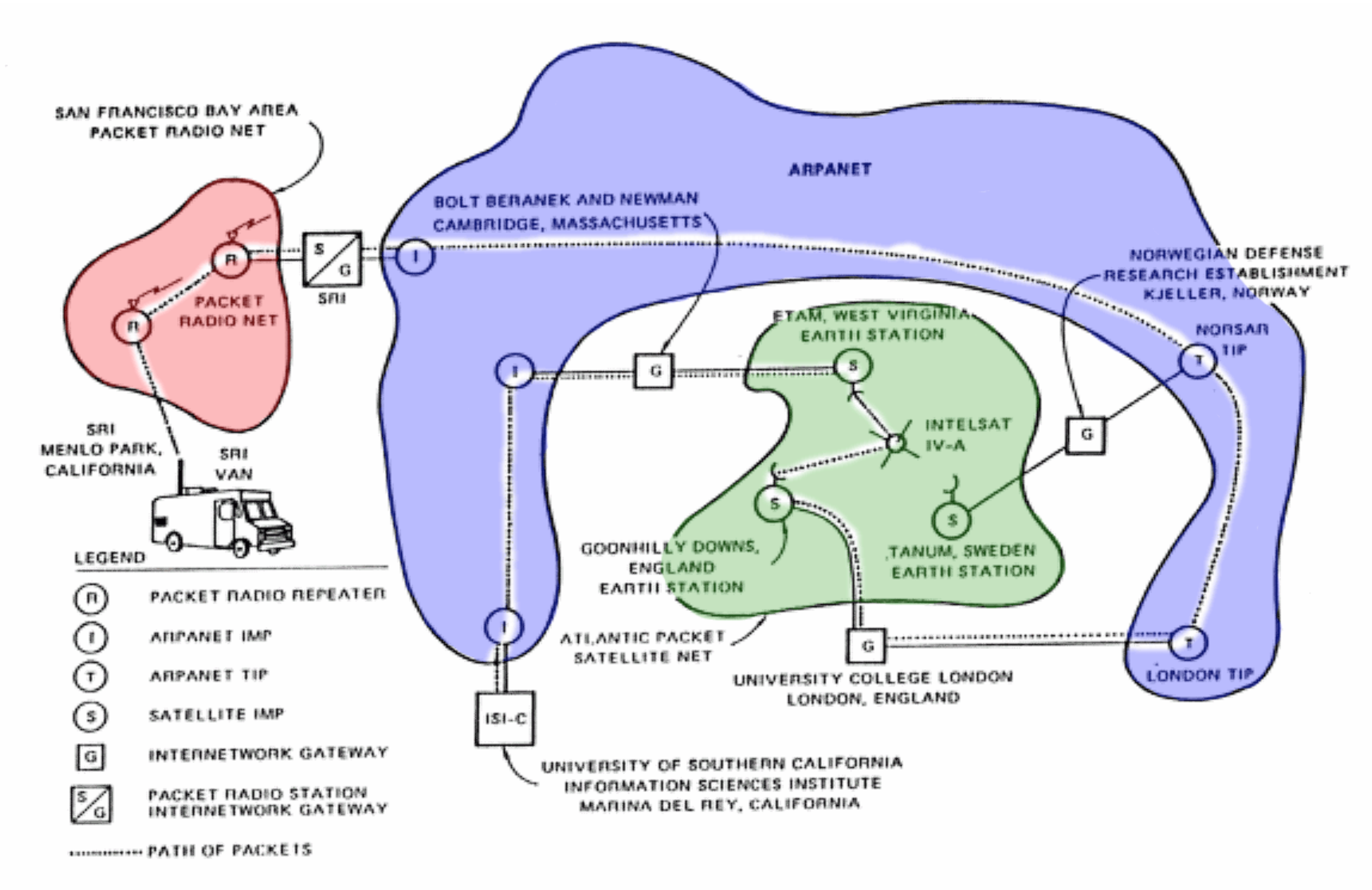


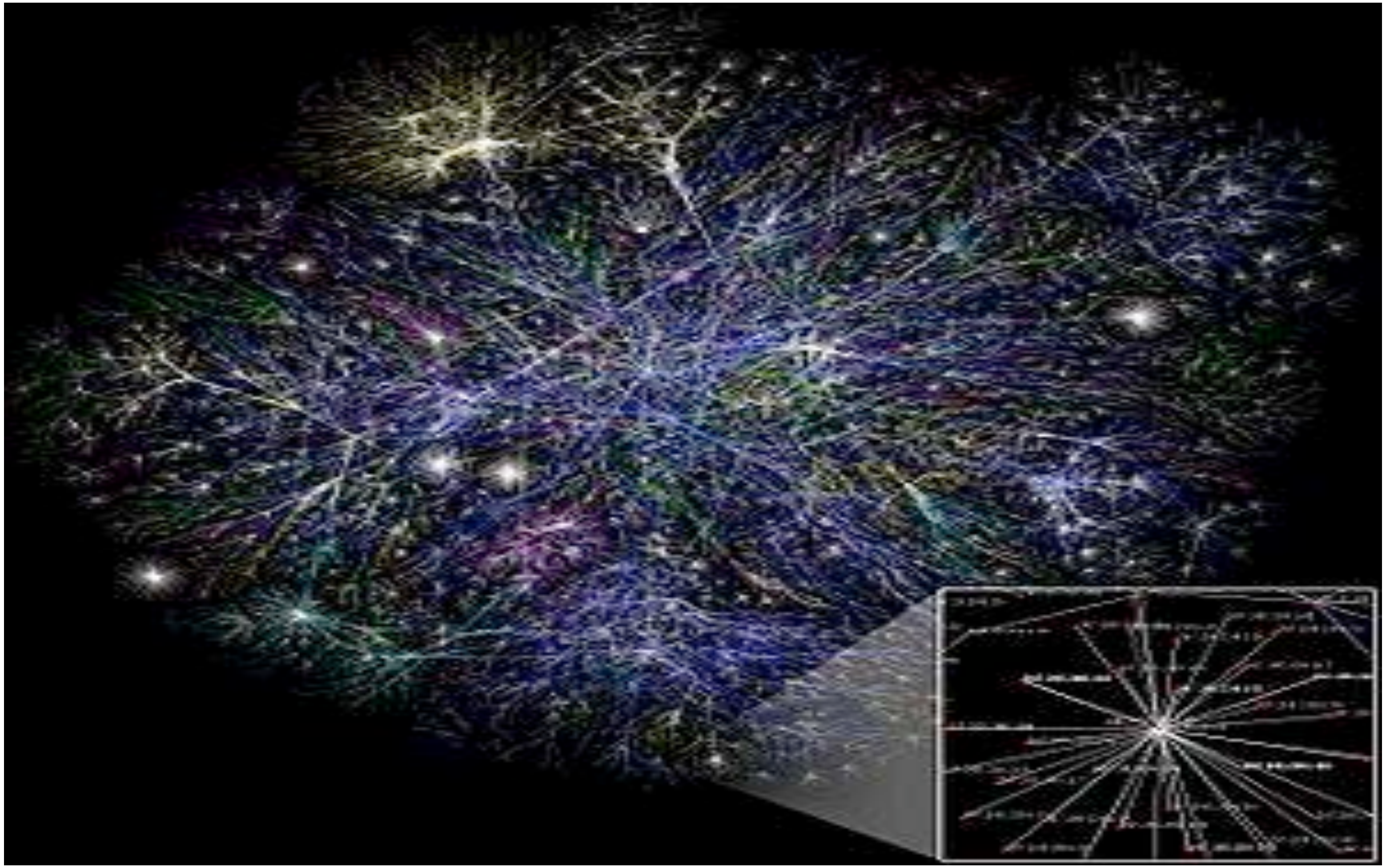
Abb. 4 ARPA NETwork, topologische Karte. Stand Juni 1974.

UCL connected in July 1973 to ARPAnet

Inter-networks Demonstration 1977



Internet 2010



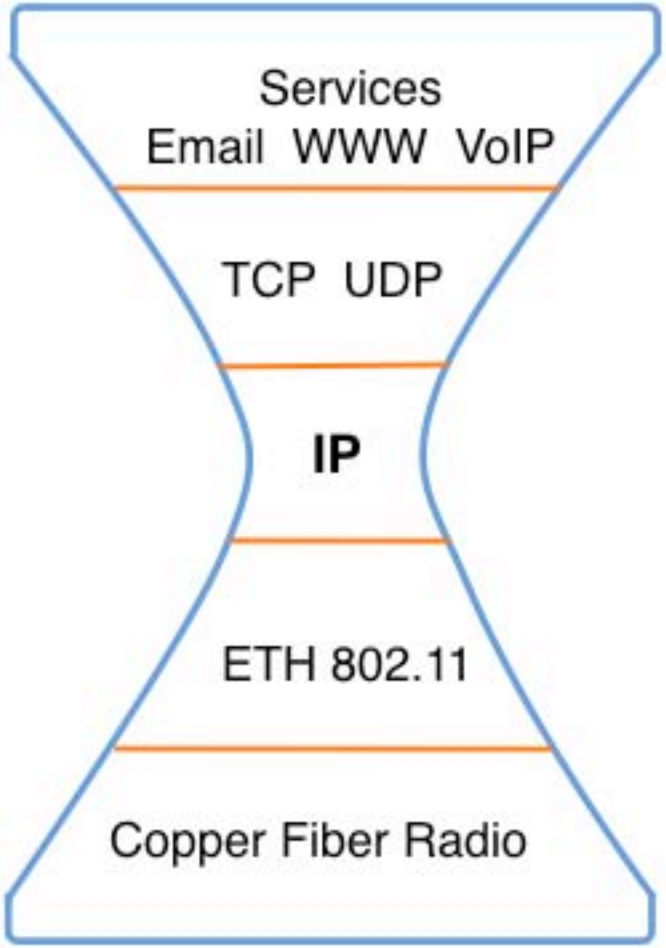
Current Internet

- The Internet plays a central and vital role in our society
  - ➢Work and business, education, entertainment, social life, …
- Victim of its own success, suffering from ossification
  - ➢Innovation meets natural resistance (e.g. no IPv6, no mobile IP, no inter-domain DiffServ, no inter-domain multicast, etc.)
- Services such as P2P, IPTV, emerging services, pose new requirements on the underlying network architecture
- Big growth in terms of the number of inter-connected devices but slow growth in innovation and new services

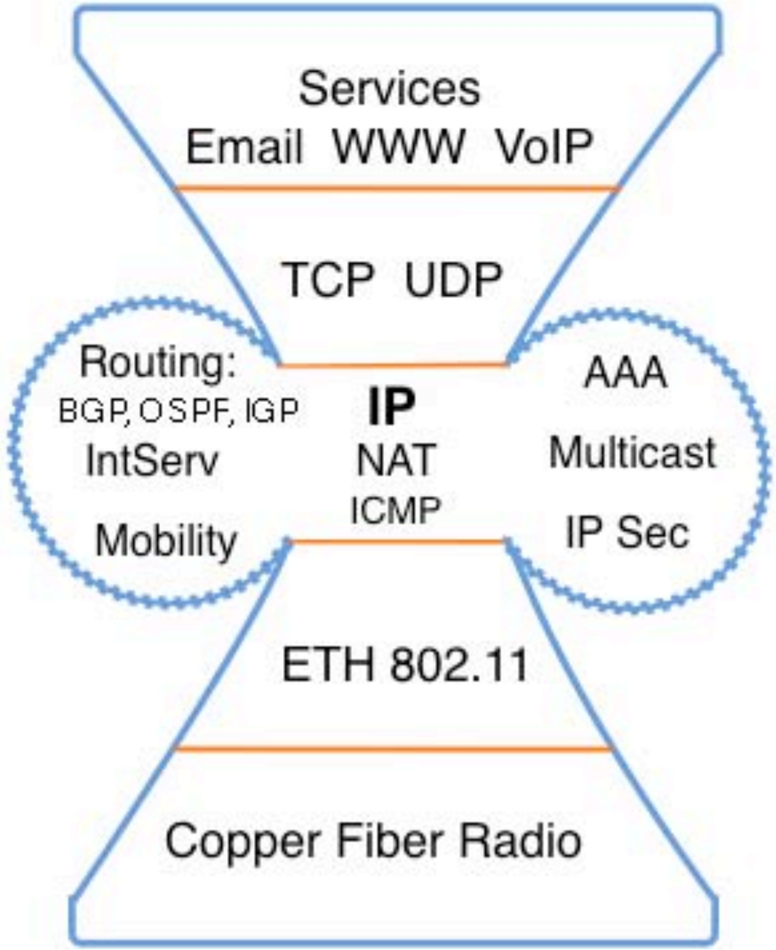
Key Changes in Internet - History

- Changes were possible when the Internet was still an academic research network (i.e. until 1993 when the WWW turned it to a commercial)
- Inter-network that underpins the “information society”
- Key changes in that period were the following: 1982 DNS, 1983 TCP/IP instead of NCP, 1987 TCP congestion control, 1991 BGP policy routing, 1991 SNMP
- No significant changes since then apart from MPLS which has been deployed in addition to plain IP
- Research efforts towards the Future Internet: evolutionary & clean-slate approaches, evolutionary changes, autonomic management

Internet Hour-glass Model



Data Plane



Control Plane

Why to change

Current Internet = Network of Interconnected uncoordinated networks

- N x 10^9 connectivity points - **status: reaching maturity and maybe some limits**
- N x10^5 services /applications **- status: fast growing**
- N x10^3 exabytes content**- status: fast growing**
- Cost structure: 80% (→90%) of lifecycle costs are operational and management costs - **status: reaching crisis level**
- Change Capability - **status: ossification reaching crisis level; a lot of missing and interrelated features; missing enablers for integration of Nets, Services, Content, Storage, …**

How to change

Approach:

- Parallel Internets; Progressive changes; “Clean” slate and evolutionary
- Network of networks → system of coordinated service networks
- Virtualization of resources (Networks, Services, Content, Storage)
- Programmability
- Increased self-managebility as the means of controlling the complexity and the lifecycle costs

Research Initiatives

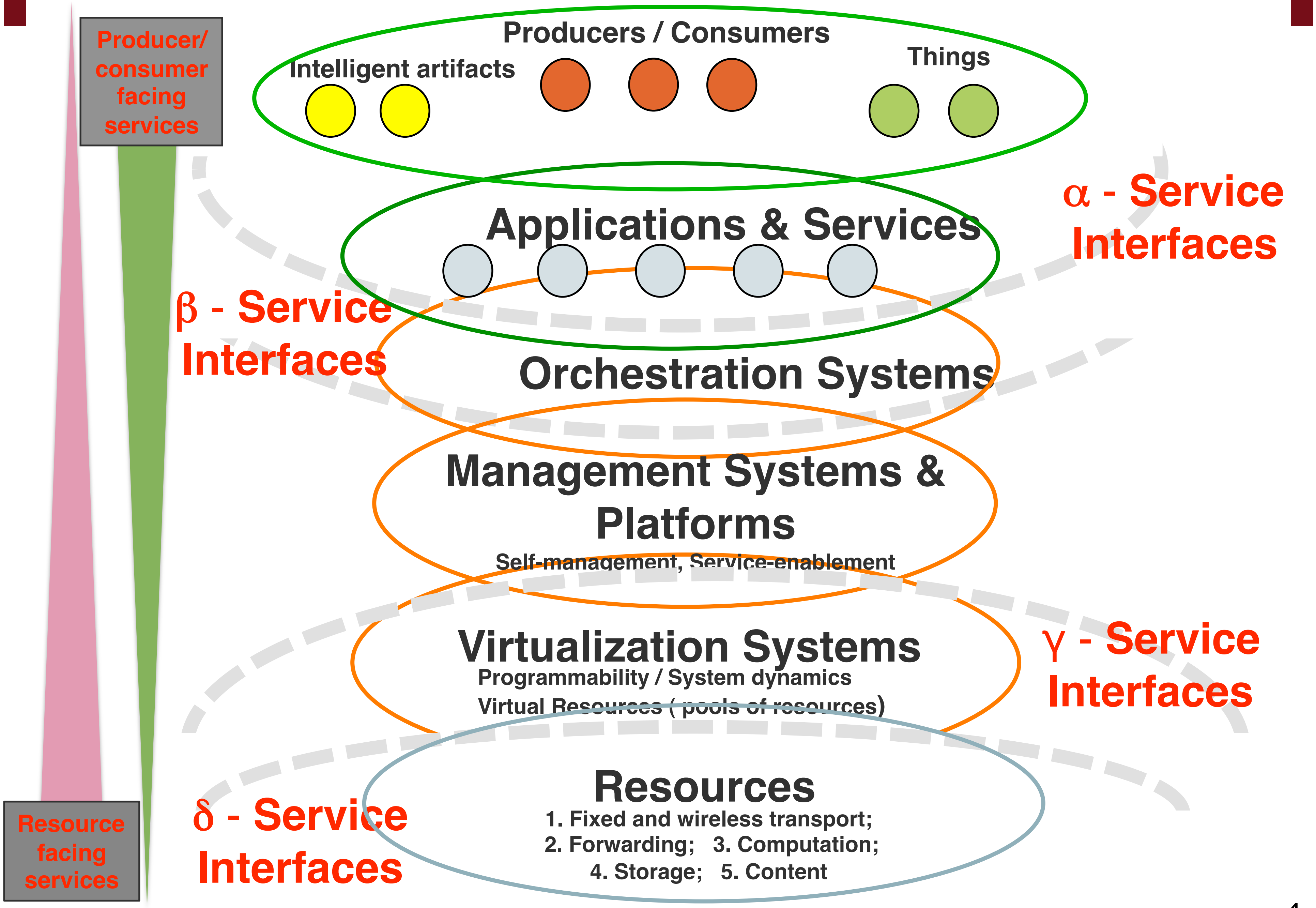
1. Korea - Future Internet Forum - http://fif.kr/
2. Asia Future Internet - http://www.asiafi.net/
3. Japan - AKARI Future Internet - http://akariproject.nict.go.jp/eng/conceptdesign.htm
4. USA - Global Environment for Network Innovations (GENI) - http://www.geni.net
5. European Union - Future Internet Assembly (FIA) www.future-internet.eu

Future Internet Research Challenges

A position paper : Management and Service-aware Networking Architectures (MANA)

EU Future Internet Assembly (FIA) www.future-internet.eu

http://www.future-internet.eu/fileadmin/documents/prague_documents/MANA_PositionPaper-Final.pdf


Producer/
consumer
facing
services
Producers / Consumers
Intelligent artifacts
Things
α - Service
Interfaces
Applications & Services
β - Service
Interfaces
Orchestration Systems
Management Systems &
Platforms
Self-management, Service-enablement
Virtualization Systems
Programmability / System dynamics
Virtual Resources (pools of resources)
γ - Service
Interfaces
Resources
1. Fixed and wireless transport;
2. Forwarding; 3. Computation;
4. Storage; 5. Content
δ - Service
Interfaces
Resource
facing
services

MANA General Challenges

- Availability of services – anywhere anytime seamless migration all according to SLA and high- level objectives.
- Connectivity anywhere and anytime, meaning the possibility to connect everywhere.
- Manageability anywhere and anytime with an increase level of self-management - as the networked systems become more and more complex this is a necessity as well as an enabler for evolution.
- Mobility anywhere and anytime.
- Adaptability everywhere to changes in context and environment.
- Dependability, resiliency, and survivability to withstand threats and (D)DOS.
- Robustness and stability, including support for mission critical applications.
- Accountability anywhere and anytime - to ensure the possibility of tracking actions performed by a user or a management agent that might impact the networked systems and their performance.
- Evolvability as an inherent feature to ensure the possibility to evolve the networking systems in a smooth way without major disruptions.
- Scalability with respect to features and functions, as well as complexity.
- Trust and security ensuring that users make use of the networks and services in a secure environment.
- Multi-domains to allow for different administrations, technologies, and parallel or federated Internets.
- Support of heterogeneity for possible technology optimisation.
- Openness towards application and services enabling the Internet Openness.
- Energy efficiency of the systems architectures, protocols, and radio spectrum; the use of the networked systems for control of energy consumption.

MANA Infrastructural Challenges

Infrastructure Components:

- Core Nodes, for the provisioning of high-speed, high volume traffic flows for data processing functions (i.e. in the core we are moving from gigabit networks to terabit/s), including flexible control and management capabilities.
- Edge Nodes and Service Nodes, for the programmatic provisioning of the transport, computational, storage, and content resources needed to deploy wide-area services, plus new network functionality, including programmability of the network forwarding functions and flexible control and management capabilities.
- Mobile Nodes and Wireless Nodes, for the programmatic provisioning of the communication, forwarding, and computational resources needed to deploy wide-area services and new network functionality within a wireless or mobile network, including programmability of the network functions and flexible control and management capabilities. Access to wireless infrastructure will also require new, higher capacity radio technologies.

Infrastructure Virtualisation Components:

- Virtual Nodes, as packages of virtual resources, involved in the creation and management of a virtual slice of wired and wireless network, computing, and storage resources in support of a service.
- Programmable networks for the provision and control of networked resources for network clouds.
- Programmable data and service centres for the provisioning of networking computational resources for service clouds.
- Soft nodes with programmability of the control, management, and service logic.

MANA Control and Elasticity Challenges

Cognitive Control:

- Uniform, open control frameworks for the FI. These have to be scalable and dynamic, yet be able to serve diverse operational and business requirements. Federation and composition of control frameworks for resources and systems are required.
- Explicit decoupling of the control (i.e. basic routing, content-based routing, source-influenced routing, and value added functions) and transport (i.e. forwarding) planes.
- Mechanisms for flexible data transport, including many relevant transport sub-layers between UDP and TCP; decoupling congestion control from the data transmission. The transport protocol functionality self-adaptation to the service requirements (e.g., level of reliability, QoS etc.).
- Mechanisms for a congestion control sub-layers with generalised fairness based on socio-economic models.
- Mechanisms for publish/subscribe - based inter-networking, aiming for a balance of network incentives and roles between the sender and the receiver. Information based publish / subscribe routing protocols are required.
- Uniform and self-configurable mobility frameworks for FI.
- New naming frameworks, including both channel identity and location, endpoints (source & destination points)-to-location resolution, identity/location splits, and support for addressing and observability of information, context objects and services at all relevant levels and layers as depicted in the MANA architectural model.

Control Operations:

- Systems and mechanisms for orchestration of all distributed control systems (i.e. an orchestration plane).
- An in-network control plane, where the distribution level can be tuned from a fully distributed scheme to a centralized scheme, with an option for intermediate ad-hoc control overlay.
- New tuneable protocols for different layers of the protocol stack in support of cleaner cross-layer interaction and dynamic service composition and collaboration.
- Flexible and cost effective operations of service platforms over core and edge transport networks.
- Mechanisms and interfaces to accommodate the conflicting interests of stakeholders in the FI architecture.
- Multiple and parallel paradigms: Anytime-Anywhere, Anytime-Somewhere, Sometime-Somewhere-When it is optimal (e.g. cheap, etc.), Sometime-Somewhere-As with required qualities (e.g. QoS, security, etc.).
- Interworking with the existing Internet.

MANA Accountability Challenges

- **Cross layer optimization, resources, network, transport and service layers - to enhance session-less application driven QoS approaches.**
- **Resource Pooling, for a cost effective way for the Internet to achieve high network utilization and secure future innovation where separate network resources behave like a single large pooled resource.**
- **Multi Transport Congestion Protocol, this combines multipath routing with congestion control and allows traffic to move away from congested links.**
- **Enhanced Service Control, enables increased control to the application when applications are best placed to choose the best path for transmission (e.g. low cost path) and manage mobility and multi-homing.**
- **Enhance Information exposure, where traffic carries info about its resource usage in such a way that the network can monitor the cost (e.g. impact on congestion) of a specific data flow but also the application can select one of the suggested paths from the network protocol to send specific traffic. The monitoring overhead may be traded to monitoring accuracy in case of limited resource availability.**
- **Lightweight Control Architecture, to avoid locating any mechanisms at network resources themselves for resolving usage conflicts with most of policing and management located at the 'enforcement point' – network ingress where customer attaches.**
- **Separate policy and mechanisms, which need common mechanisms across the infrastructure to control resource usage while the policy can be left under the control of the various stakeholders.**
- **Development of credible accountability mechanisms for various actors of the FI.**
- **Mechanisms for handling non-technical aspects of accountability such as legal, governance and ethical issues.**

MANA Virtualization Challenges (1)

Virtual Resources:

- Ubiquitous Virtual Resources with integrated self-management of those resources. This allows for the integrated and flexible usage of heterogeneous and assumable virtual resources for wired and wireless networking, for computation, for storage, for content, and for mobility.
- Virtual assurable groups of resources, which do not necessarily correspond to administrative, topological, or geographical domains. This would take into account concerns such as confidentiality, availability, integrity, and safety; they can be used to enable collaborative groups of consumers to exchange information in pursuit of shared interests, services, or business processes.
- Resource allocation to virtual infrastructures or slices of virtual infrastructure.
- Auditability of virtual resource consumption. Virtual /real resource contracts, RLA – resource level agreements, will be constructed.
- Security concerns related to the use of virtual resource and their management.

Virtual Infrastructure, Operation and Systems:

- Dynamic creation and management of virtual infrastructures/slices of virtual infrastructure across diverse resources.
- Dynamic mapping and deployment of a service on a virtual infrastructure/ slices of virtual infrastructure.
- Inter-working, inter-operability, and federation of virtualised infrastructures.
- Inter-cloud trading and brokering of virtual resources.
- Self-Management and manageability of Virtual Clouds (Network Clouds, Service Clouds, Virtual Infrastructures).
- Composition / decomposition of Virtual Clouds (Network Clouds, Service Clouds, Virtual Infrastructures).
- Programmability and cross-layers programmability of Virtual Clouds (Network Clouds, Service Clouds, Virtual Infrastructures).

MANA Virtualization Challenges (2)

Virtual Infrastructure, Operation and Systems:

- Secure and on-demand virtual infrastructure provisioning (programmatic access, sustainable federation, automated system management).
- Mechanisms for managing trust between the virtualised infrastructure and the users.
- Virtual resource-facing services enabling flexible usage of the physical resources.
- Increased level of service-aware virtual/real resource control.
- Agility in virtual/real resources; including dynamic re-negotiation of service configuration.
- Real-time service computing clouds and virtual-private service clouds, integrating the necessary storage, networking, and service resources.
- Ubiquitous light-weight virtual channels for integrating an Internet of Things into a service-aware network infrastructure.
- Service Clouds viewing the virtual and real network as a service.
- Service Clouds: application as service in a Cloud, platforms in the Cloud, Infrastructure Clouds, network infrastructure as a service in the Cloud; Federated Clouds with Networks for business applications.
- Increased level of automation and autonomicity in the Service Clouds.
- Overlays for enabling decentralized component interactions and for the provisioning of virtualisation of the infrastructure resources; overlays for creating a topology of nodes for the interactions of different components.

MANA Self-management Challenges (1)

Self-functionality Mechanisms:

- Cross-domain self-management functions, for networks, services, content, together with the design of cooperative systems providing integrated management functionality of system lifecycle, autonomicity, SLA, and QoS.
- Embedded and inherent management functionality in most systems in the FI, such as in-infrastructure management, including in-network management and in-service management.
- Mechanisms for dynamic deployment on-the-fly of new management functionality without running interruption of any systems. The operations required are: Plug-and-Play, Unplug-and-Play, and (re)programmability of the forwarding and control planes.
- Mechanisms for dynamic deployment of measuring and monitoring probes for service and network behaviours, including traffic. Mechanisms for monitoring algorithms and frameworks. SLA-aware sensing and continuous monitoring of systems' adaptations. Adaptive SLA-aware infrastructure. Use of monitoring services in support of the self-management functionality.
- Mechanisms for high performance distributed triggering frameworks and event management (transport, correlation/composition).
- Mechanisms for distribution and use of monitoring probes information; configurable and programmable distributed real-time monitoring of all subsystems.
- Mechanisms for conflict and integrity-issues detection and resolution across multiple self-management functions and policies.
- Mechanisms for optimising tradeoffs between the requirements of multiple systems.
- Mechanisms for intelligent and efficient decision-making where there are multiple participating entities.
- Mechanisms, tools, and methodology for the verification and assurance of different self-capabilities that are guiding systems and their adaptations correctly.
- Mechanisms for allocation and negotiation of different resources. High flexibility in resource control.
- Mechanisms for unified information modelling and storage as a support to context building.
- Mechanisms for support of new/enchanted information modelling of MANA nodes or elements
- Mechanisms for fault diagnosis and possibly self-repair able to cope with incomplete or erroneous management information.
- Mechanisms for self-adaptation of management functions.
- Mechanisms for context-awareness of cross-stratum (communication, storage, content, and computation sub-strata) interaction.
- Mechanisms for socio-economic model based management, which enable control and optimisation of systems life costs.
- Mechanisms for use and development of appropriate ontologies for self-management and orchestration systems.
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MANA Self-management Challenges (2)

Self-functionality Mechanisms:

- Mechanisms for controlling and stabilizing the behaviour of nodes and systems in the context of continuous triggers and changes made autonomously, or in response to inputs (events or programming). Detection and management of normal /abnormal behaviour (i.e. security, intrusion, resources failure and/or malfunction). Explicit relationship between behaviour management, socio-economics and uncertainty.

Self-functionality Infrastructure and Systems:

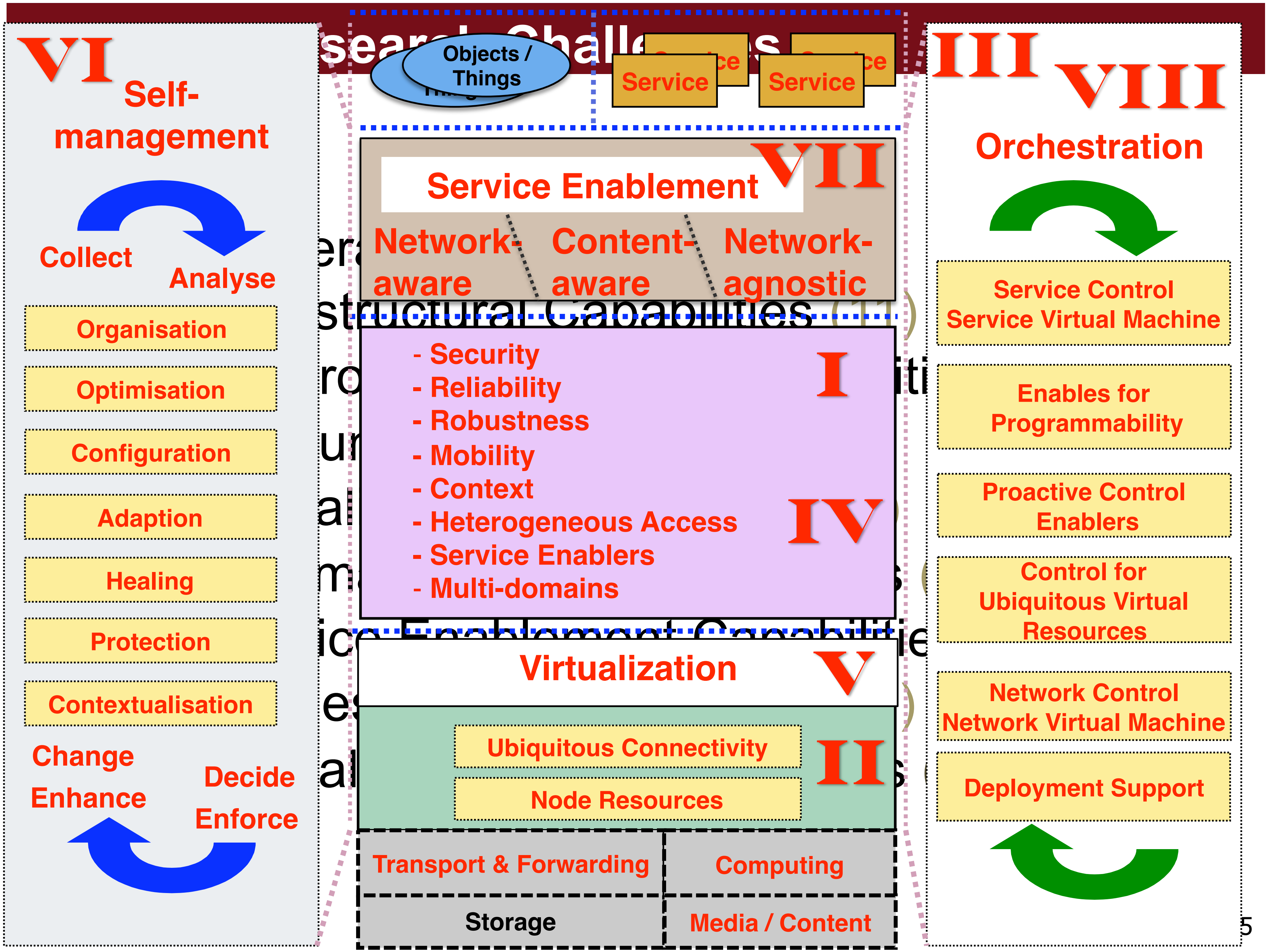
- Increased level of self-awareness, self-stability, self-configuration, self-organisation, self-optimisation, self-healing, self-protection, self-adaptation, self-contextualisation, self-assessment and self-management capabilities for all FI systems, services, and resources.
- Increased level of self-adaptation and self-composition of resources to achieve effective, autonomic and controllable behaviour.
- Increased level of self-contextualisation and context-awareness for network and service systems and resources.
- Efficient resource management frameworks, including discovery, configuration, deployment, utilization, control and maintenance.
- Automated auditing and traceability of the decisions and changes triggered by the management systems.
- Increased level of cost effectiveness of resources' usage, of system operations and of management operations (monitoring, computations, control, change) and of self-awareness.
- Self-awareness capabilities to support system-level objectives of minimizing system life-cycle costs and energy footprints.
- Self-awareness capabilities for managing operations in time of crisis
- Orchestration as a system of management systems (i.e. bootstrapping, workflow of control, interactions and update of the management systems). Service driven dynamic orchestration. Programmability of the orchestration plane.
- Capabilities for the control relationships between Self-Management and Self-Governance of the FI.
- (Re)establish fundaments of the management of FI by revisiting the science and the mathematics.
- Several degrees of freedom to the design of management functionality for FI (degrees of embedding, degrees of autonomicity, degrees of abstractions, degrees of costs, degrees of manageability; allow clean slate and migration paths). Allow only degrees of freedom that are associated with guaranteed stability.
- Trust in self-management systems.
- Assessment/proof methodologies, mechanisms and technologies of individual self-* capabilities – aposteriori (i.e. benchmarking) and possibly a priori (e.g. by means of simulation or emulation).

MANA Service Enablement Challenges

- Network services exposed for consumption are virtual, enabling them to be:
  - instantiated at run-time over physical resources based on negotiated features (or requirements upon termination of SLA, freeing up physical resources for new use.
- Network service interfaces discoverable by consuming services using standard languages and protocols.
- All relevant service parameters detailed in the service interface.
- A negotiation service, which supports SLA contracting with consuming services.
- Transparent monitoring, logging, and exception handling to track potential) such as bandwidth/throughput, security, spatialness, etc.
  - managed at runtime with SLA compliance as an objective.
  - torn down SLA violations.
- Network accounting tracks service violation penalties.
- Details of service contracts available to network autonomics so that SLAs can be enforced hierarchically at runtime.
- Run-time network management comprehending details of SLAs in place, when making decisions on infrastructure allocation, as well as negotiating incoming SLAs.

MANA Orchestration Challenges

- Mechanisms for controlling workflow for all systems of all FI system-of-systems, ensuring bootstrapping, initialisation, dynamic reconfiguration, federation, adaptation and contextualisation, optimisation, organisation, and closing down of service components.
- Mechanisms to control co-existence of multiple and parallel FI(s) based on multiple socio-economies matrices and measures.
- Mechanisms for distributed governance.
- Mechanisms to control the sequence and conditions in which one service component invokes other service components in order to realize some useful function.
- Mechanisms for negotiation in order to solve conflicts among FI systems. Negotiation can also occur between different domain systems.
- Mechanisms for allowing conflicting interests (the so called “tussle networking” introduced by D. Clark) such as conflicting policies, traffic patterns, different compensation approaches and different operations.
- Mechanisms for the dissemination of knowledge regarding the Orchestration Plane.
- Mechanisms for FI federation: these control the union/separation of network and service resources having different autonomic management domains. They identify the steps necessary to compose/decompose different federated domains, triggering actions to change the networks and services.
- Mechanisms for controlling the information flow. They define the “What, When and Where” of the information: What information to collect, when to collect, and from whom (where). They supervise the storage of information.
- Mechanisms for cognitive control. They define system data collection, management and decision making, which enable the Internet infrastructure to learn about its own behaviour, to tune its operation, and to enforce its decisions on data manageability.
- Mechanisms for bootstrapping and initialisation systems under supervision.
- Mechanisms for dynamically reconfiguring and adapting of other systems under supervision.
- Mechanisms for dynamically optimising and organising other systems under supervision.
- Mechanisms for dynamically closing down of other systems under supervision.
- Mechanisms for supervision of QoS controllers, triggering an instantaneous modification of the configuration. For example, when following a failure, an instantaneous reconfiguration of the virtual systems is necessary.
- Mechanisms for supervision of resource allocation in several virtual systems. For example, this capability would trigger a change in resource allocations following changes in the context.
- Mechanisms and ontologies that describe the functionalities and enable dynamic discovery, understanding and interaction with the respective offered capabilities.
- Mechanisms to create holistic network view from separate views of the elements in all network level and in all virtualization levels.
- Mechanisms to allow nesting of different control loops with respects to the same objective or the same set of resources.


VI
Self-management
Collect
Analyse
Organisation
Optimisation
Configuration
Adaption
Healing
Protection
Contextualisation
Change
Enhance
Decide
Enforce
Objects / Things
Service
Service
VII
Service Enablement
Network-aware
Content-aware
Network-agnostic
I
- Security
- Reliability
- Robustness
- Mobility
- Context
- Heterogeneous Access
- Service Enablers
- Multi-domains
IV
Virtualization
V
Ubiquitous Connectivity
Node Resources
II
Transport & Forwarding
Computing
Storage
Media / Content
III
VIII
Orchestration
Service Control
Service Virtual Machine
Enables for Programmability
Proactive Control Enablers
Control for Ubiquitous Virtual Resources
Network Control
Network Virtual Machine
Deployment Support

Summary & Conclusion

- The Future Internet will possibly be more dynamic, allowing more user control
  - It will pose much more difficult management challenges
- In-system autonomic management enabling self-management via closed loops feedback control
  - Better management functionality that is not an afterthought
  - Potentially better services and cost-cutting
  - We have already some of the elements of autonomic management but we need advances in various areas

Q&A