# A Review of Next Generation Internet Architecture Open-Source Software Projects

Towards a Human Centric Internet

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***Abstract*—Internet and web technologies have evolved over the past 50 years to a patchwork of architectures, frameworks, applications/services and protocol stacks, with many actors contributing solutions as well as novel uses of the technology emerging rapidly. A drive from the European Commission (EC) called Next Generation Internet (NGI) supports developers, researchers and entrepreneurs towards building a human-centric Internet, focusing on privacy and trust as central themes and building contributions based on Open-Source Software (OSS). This paper reviews 32 projects supported by the EC in terms of their OSS community contributions and the planned sustainability of their solutions and organisation.**

***Keywords* — Internet architecture, network, transport, applications, services.**

## I. INTRODUCTION

This article presents work in progress of an analysis of Next Generation Internet projects regarding their financial sustainability and overall contribution to the evolution of Internet Architecture. It includes projects covering all layers of the Internet and its core applications and new communication paradigms on decentralisation.

In 2017, a new European initiative called the Next Generation Internet was created to support European values in the future development of the Internet and related technologies. Robert Viola states in his speech [1]:

*"When policy-makers, researchers and society reflect on the future evolution of the Internet, we should take a fresh look at all these issues. The Internet should offer more to the people and to our society, providing better services and greater involvement and participation. It should be designed for humans, so that it can meet its full potential for society and economy and reflect the social and ethical values that we enjoy in our societies."*

The rest of the paper is structured as follows. Section II introduces the background of the data, followed by the categorisation of the projects in Section III. The most significant cases are described in Section IV. Section V proposes future research and conclusion. The article is finalised with acknowledgement for the projects which allow data collection and research work within open-source projects.

## II. BACKGROUND

Data for this article originates from the NGI Pointer [2] project. NGI Pointer supported a total of 36 OSS projects with grants ranging from 50,000EUR to 200,000EUR to develop topics around Next Generation Internet Architecture. A total of 250 applicants were evaluated. An independent committee of experts selected the projects based on a set of common criteria. The project addressed topics included: Privacy-by-design; Internet at the Edge; Network Optimisation; Virtualisation and isolation; Limitations in the TCP/IP protocol suite; Autonomous Network operations and control; Energy efficiency; Industrial Internet Security; Trust for New Internet/Web Users.

32 out of the 36 projects are studied in this research article. Three projects were excluded due to the limited information the projects provided publicly. One project (Nyxt) received two separate grants from NGI Pointer and is treated as one project for this research work.

All data collected in this research is publicly available on the various websites of the projects, organisations and code repositories (See Tables 1-3). The data was collected over a period of three years, starting in January 2020, with the project to conclude in December 2022. Several interviews, dialogues and a podcast series helped enrich the information and clarified ambiguous data. The podcasts are available publicly [3].

## III. CATEGORISATION OF PROJECTS

The Internet architecture can be broken down into six layers [4]. In this article, the six layers are bundled into:

- Applications and Services:
  - Specific applications and services
  - Application protocols
- Network and Transport Layers
  - Transport protocols
  - Network protocols
- Other
  - Data-link protocols
  - Physical layer protocols

The "other" category also includes projects that do not fall strictly into any other layers, such as hardware projects related to chip design or chip design tools and communication systems spanning several layers.

## IV. REVIEW OF NEXT GENERATION INTERNET CASES

Tables 1-3 provide a complete list of the studied projects. Furthermore, a few of them must be highlighted as particularly interesting projects.

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### A. Case Examples

SCION is an initiative that has been ongoing for over a decade, with over 50 individuals, mostly from research, participating in the development of SCION [5]. The contribution from NGI Pointer is a public grant to develop a specific mechanism called VerfiedRouting for SCION. SCION, as such, is then a publicly funded open research project. However, alongside the development as an open research project, the founder and founding university created a spin-off called Anapaya that also monetises SCION through corporate distribution and offers consulting-style services around the technology to customers, mostly financial institutions and Internet Service Providers.

WireGuard is a straightforward yet fast and modern VPN that utilises state-of-the-art cryptography [6]. It was initially released for the Linux kernel but has since been ported to all major operating systems. The project is a large open community project that has largely been supported by public funds, however, the key persons behind the technology also operate consultancies offering consulting services in cyber security, amongst other topics. In addition, Wireguard is now provided via Mozilla as a corporate distribution. Finally, WireGuard also accepts donations to the project via its website.

Ltt.rs is a user-friendly and encrypted by default e-Mail client for Android based on modern standards like JMAP (RFC8621) [7] and Autocrypt [8]. Using JMAP instead of IMAP makes the app more maintainable and reliable on current mobile operating systems due to the built-in push capabilities. Ltt.rs is sponsored via public funding but simultaneously offers a small-scale corporate distribution of the application as a freemium/premium application.

Nyxt is a keyboard-driven web browser designed for power users. Inspired by Emacs [9] and Vim [10], it has familiar key bindings and is infinitely extensible in Lisp. For example, users can switch between tabs by topic or URL, search all URLs on a page by name or target, search through all of the bookmarks with compound queries, etc. Nyxt focuses on corporate distribution as a freemium/premium application, where the basic version of the browser is free to use, and tools, as well as add-ons, become part of a subscription-based service at a premium. Additionally, the team behind Nyxt is offering consulting services.

The PANAPI [11] project designs a sophisticated host-based network-path selection engine on top of the SCION [5] network architecture and provides it as an open-source implementation of the abstract next-generation transport service API, currently being drafted in the IETF TAPS Working Group. The project is an OSS-sponsored project and predominantly an open research project with contributions to standards.

## V. Conclusion and Future Work

This article presents a first look at 32 projects under the umbrella of the NGI. The aim is to analyse the projects from a financial sustainability perspective and gain a more general understanding of how to support and grow future Internet initiatives through public, private and community support. More projects need to be studied to find more evident trends and develop a model of modern Business Model Patterns for open-source software and hardware projects driven by European Values under the NGI.

A suggested framework for such analysis is based on [4], but other theoretical and practical studies should be considered.

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TABLE 1. OTHER PROJECTS

| Name | Description | Contributors |
|---|---|---|
| **Mirage OS** [24] | MirageOS is a library operating system that constructs unikernels for secure, high-performance network applications across various cloud computing and mobile platforms. Developers can write code on traditional operating systems such as Linux or macOS. They can then compile their code into a fully-standalone, specialised unikernel that runs under the Xen or KVM hypervisors and lightweight hypervisors like FreeBSD's BHyve, and OpenBSD's VMM. These unikernels can deploy on public clouds, like Amazon's Elastic Compute Cloud and Google Compute Engine, or private deployments. | Medium 10-100<br>https://github.com/mirage/mirage |
| **BANG** [25] and [26]<br>The official project title is European Firmware and App Library | BANG is a framework for processing binary files (like firmware). It consists of an unpacker that recursively unpacks and classifies/labels files and separate analysis programs that work on the results of the unpacker. | Small <10<br>https://github.com/armijnhemel/binaryanalysis-ng |
| **Solid Shape** - Reshaping Linked Data on the Fly [27] | The project implemented an open-source registry of linked data shapes and forms. A registry of linked data shapes and forms is an essential part of the Solid ecosystem, and the execution of this project will accelerate Solid's adoption. | Small <10<br>https://github.com/digita-ai/semcom/ |
| **LKRT**<br>Linux kernel regression tracking | Build and integrate mechanisms into the Linux kernel development processes to track all regressions reported by humans or CI systems. Together with the existing "no regression" rule, this will help ensure new releases with improved security techniques work as well as their predecessors. | Small <10<br>https://gitlab.com/knurd42/regzbot<br>https://linux-regtracking.leemhuis.info/post/regzbot-approach/ |
| **KORUZA**: Wireless Optical Communication System for Urban Environments [28] | KORUZA is a wireless optical communication system based on the FSO technology for urban environments, designed for last-mile, 5G and IoT applications. It uses an eye-safe collimated beam of IR light for point-to-point data transmission through the air. The solution avoids digging up roads, allowing distances up to 150m with fibre-like speeds of 1-10 Gbps. | Small <10<br>https://github.com/IRNAS/koruza-v2-pro |
| **Libre EDA** | LibrEDA is a libre software framework for the physical design of silicon chips. A strong motivation is democratising silicon technology by making ASIC toolchains accessible for research, education and hobbyists. | Medium 10-100<br>https://codeberg.org/LibrEDA |
| **Libre SOC** | The LibreSOC Project brings an ethically developed privacy respectful, power-efficient SoC to the world. Full source to the bedrock. No spying backdoor co-processors. No leaked firmware keys. Fully transparently developed. | Small <10<br>https://git.libre-soc.org/ |

TABLE 2. APPLICATIONS AND SERVICES PROJECTS

| Name | Description | Contributors |
|---|---|---|
| **Ltt.rs** - Open Source E-mail client | Ltt.rs is a user-friendly and encrypted by default e-Mail client for Android based on modern standards like JMAP (RFC8621) [7] and Autocrypt [8]. Using JMAP instead of IMAP makes the app more maintainable and more reliable on current mobile operating systems due to the built-in push capabilities. | Medium 10-100 https://github.com/iNPUTmice/lttrs-android |
| **DREAM**: Replicable extensible agency machine | The project enables the convergence of distributed peer-to-peer (P2P) networks and linked data models within a social solidary economy and organisation among trusted groups. | Small <10 https://gitlab.com/public.dream |
| **Nyxt** Browser | Nyxt is a keyboard-driven web browser designed for power users. Inspired by Emacs [9] and Vim [10], it has familiar key bindings and is infinitely extensible in Lisp. For example, users can switch between tabs by topic or URL, search all URLs on a page by name or target, Search through all bookmarks with compound queries, etc. | Large 100-1000 https://github.com/atlas-engineer/nyxt Note: The Nyxt Browser project was split into two parts during NGI Pointer. |
| **Lightmeter** | Lightmeter makes it easy to run e-mail servers by visualising, monitoring and notifying users of problems and opportunities for improved performance and security. People regain control of sensitive communications either directly by running their own mail servers or indirectly via the increased diversity and trustworthiness of mail hosting services. | Medium 10-100 https://gitlab.com/lightmeter/controlcenter Note: since the completion of the project, Lightmeter has received venture funding via Y-Combinator |
| **Scuttlebutt** - The Gossip Protocol | Scuttlebutt (SSB) is an edge computing, peer-to-peer communications protocol. | Medium 10-100 https://github.com/dominictarr/scuttlebutt |
| **P2Panda** | p2panda + Bamboo + OpenMLS p2panda is a user-friendly peer-to-peer communications protocol with browser support, local deletion, fork detection, efficient partial replication, large-scale group messaging encryption and future-proof schema migrations to build secure and user-friendly applications. p2panda has been in development since 2019, focusing on prototyping and research. | Small <10 https://github.com/p2panda |
| Advanced privacy-preserving protocols for **GNU Taler** | GNU Taler is a project that offers a free software infrastructure and protocols for privacy-friendly online payments. The software is continuously extended with added features. | Medium 10-100 https://git.taler.net/ |
| **Garage**: Geo-distributed data store compatible with the S3 API | Garage is a geo-distributed data store notably compatible with the S3 API. Garage makes it easy to distribute the storage layer of digital services, supporting multi-cloud and on-premise deployments and even allowing household computers to join the cluster without hassle. | Small <10 https://git.deuxfleurs.fr/Deuxfleurs/garage |
| **Peergos** [23] | Peergos is building the next web - the private web, where end users are in control. For example, web apps are secure by default and unable to track individuals, and individuals control precisely what personal data each web app can see. | Small <10 https://github.com/peergos/peergos |
| **DT4DW**: Developer Tools for Decentralised Web | The essential technologies to build a decentralised web are available today, but the broader ecosystem and uptake are still in its infancy. One reason for this is a lack of developer tooling. Moving from traditional client/server architectures to building decentralised applications requires developers to replace many day-to-day debugging & testing tools with manual logging, custom scripts and guesswork. This tooling gap contributes to the significant difficulties of decentralised development today. By extending HTTP Toolkit and Mockttp to support IPFS, WebRTC and Ethereum, this project gives developers the tooling to debug and test next-generation decentralised web applications. | Small <10 https://github.com/httptoolkit |

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TABLE 3. NETWORK AND TRANSPORT LAYER PROJECTS

| Name | Description | Contributors |
|---|---|---|
| **SCE** - Some Congestion Experienced [12] | SCE is a high-fidelity congestion control signalling protocol beyond the edge and into core networks and aggregation points. | Very large >1000 https://github.com/chromi/sce |
| **WireGuard** [5] | WireGuard is a straightforward yet fast and modern VPN that utilises **state-of-the-art cryptography**. Initially released for the Linux kernel, it is cross-platform (Windows, macOS, BSD, iOS, Android) and widely deployable. | Large 100-1000 for the original linux version https://www.wireguard.com/repositories/ https://www.wireguard.com/ |
| **MTCP5G** Multipath TCP for 5G networks [13] | MPTCP is an ongoing effort of the IETF Multipath TCP working group that aims at allowing a TCP connection to use multiple paths to maximise resource usage and increase redundancy. In other words, MPTCP will allow one TCP session to be conveyed on several paths over different access networks. | Very large >1000 https://github.com/multipath-tcp/mptcp |
| **IGNNITION** Fast prototyping of complex GNN for network optimisation [14] | IGNNITION is a framework for the fast prototyping of Graph Neural Networks (GNN). This framework allows users to design and run their own GNNs without specialised knowledge, such as TensorFlow or PyTorch. | Small <10 https://github.com/BNN-UPC/ignnition |
| **SCION** Scalability, Control, and Isolation on Next-generation Networks [5] | SCION is the first clean-slate Internet architecture designed to provide route control, failure isolation, and explicit trust information for end-to-end communication. | Medium 10-100 https://github.com/scionproto/scion |
| **REOWOLF** [15] | Reowolf replaces sockets with connectors which support high-level verification, compilation, and optimisation techniques. | Small <10 https://gitlab.com/nl-cwi-csy/reowolf |
| **MPTCP** analyser [16] | The MPTCP analyser is a tool to help analyse the performance of a multipath protocol and the software to auto-configure the system depending on the application objective and network conditions. | Small <10 https://github.com/ngi-mptcp/mptcpanalyzer |
| **DataHop** - Incentivised Content Dissemination at the Network Edge | DataHop is a mobile content distribution infrastructure based on smartphone device-to-device (D2D) communications. Content is pushed to source selected mobile users, hops from device to device, and spreads in the network to destination nodes. | Small <10 https://github.com/datahop |
| **EDGESec** | Edgesec defines a new architecture and toolset for edge-based routers addressing fundamental security weaknesses that impact current IP and IoT router implementations. | Small <10 https://github.com/nqminds/EDGESec |
| **TCPLS** [17] | TCPLS is an extension to Transport Layer Security (TLS) 1.3 that closely couples TLS with one of the most important Internet protocols: TCP. This allows greater extensibility for TCP by overcoming the limits of TCP Options and limiting middlebox interference. | Small <10 https://github.com/p-quic |
| **SPHINX** [18] and [19] | The Sphinx packet format provides an essential potentially standardised component for privacy-enhanced networking. | Small <10 https://github.com/nymtech/sphinx |
| **PANAPI**: Path Aware Networking Application Programming Interface [10] | The PANAPI project designs a sophisticated host-based network-path selection engine on top of the SCION [5] network architecture and provides it as an open-source implementation of the abstract next-generation transport service API currently being drafted in the IETF TAPS Working Group. | Small <10 https://github.com/netsys-lab/panapi |
| **EDGNSS**: Energy Efficiency, Edge and Serverless Computing [20] | The project revisits the Internet Architecture by leveraging Software Defined Networks (SDN) with Network Function Virtualisation (NFV) technologies to allow efficient and on-demand placement of Virtual Network Functions (VNF) on a serverless platform for energy-aware function provisioning in edge environments. | Small <10 https://github.com/EDGNSS |
| **P4EDGE** | The project develops an open-source software stack to enable the creation of accessible P4-switches based on open hardware (e.g., RaspPI, x86/ARM-based router boards) that have low cost and low power consumption and are accessible for a wide range of edge users, where moderate performance (100Mbps to few Gbps) is needed. | Small <10 https://github.com/P4EDGE |
| **RIM**: Receiver-driven Incoming-traffic Management [21] and [22] | The project evolves the Internet's resource management approach to enable receivers to execute congestion control functions, taking an active role in determining the capacity of incoming traffic. | Small <10 https://github.com/net-research/rledbat_module |

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