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Measurement and Architecture for a Middleboxed Internet

H2020-ICT-688421

Intermediate Standardisation, Dissemination, and Exploitation Report

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Executive Summary

This deliverable covers the activities related to dissemination, exploitation, and standardisation of the project, describing the key aspects of these activities and their progress since last report made in D4.2 in June 2016. The three aspects mentioned before are detailed with respect to target stakeholder groups through the relevant channels identified.

1 Introduction

The MAMI project focuses on the development of middlebox cooperation mechanisms, based on the collection and analysis of large-scale middlebox impairment measurements in the Path Transparency Observatory (PTO) and experimentation in Internet testbeds, to support deployment of ubiquitous encryption while maintaining support of in-network functionality in a cooperative way between endpoints and middleboxes.

The MAMI goals can only be achieved by means of a high impact of the project results at the scientific, industrial, and societal levels, in Europe and beyond. This requires a coordinated dissemination and outreach activity, with special emphasis on the standardisation matters, and therefore a dedicated workpackage (WP4: Standardisation, Dissemination and Exploitation) is committed to maximize the impact of the project results in all fields addressed in it.

In this deliverable we report the activities related to the external communication and dissemination of project results, the identification of targets for further industrial exploitation beyond the time scope of the project, and the steps taken to contribute to the relevant standards organizations. This is an intermediate report, and therefore many of the activities detailed here are in different degrees of advance, though we can highlight the general directions of WP4 activities:

- Identification of potential opportunities for new work towards explicit middlebox cooperation, and the preparation of appropriate technical contributions to create and influence new standards, especially within Internet Engineering Task Force (IETF) and Internet Research Task Force (IRTF) groups. With this focus a new proposed IRTF research group on path-aware networking (panrg) has been initiated by participants of the MAMI project, this group met for the first time at the IETF-99 in July 2017 in Prague.
- Input into standardisation towards the development of mechanisms for middlebox cooperation in existing and new protocols such as explicit support for in-network measurements (e.g. a spin-bit for RTT measurements in QUIC) and trust-but-verify-based service differentiation (e.g. Loss-Latency tradeoff marking (LoLa)) as well as dissemination of results of initial implementation experience and experimentation with these cooperation mechanisms. With this focus several MAMI participants are actively contributing to various standardisation working groups, such as tsvwg, quic, taps in the IETF as well as ETSI NFV, ETSI TC CYBER, IEEE ETI WG and GSMA Internet WG.
- Continuing building awareness in the research and scientific community about the project and the project's results. This concerns the middlebox cooperation mechanisms, middlebox measurements performed by various tools such as PATHspider and tracebox that have been continuously developed by the project, and the PTO to enable public access and comparison of different measurement campaigns performed by the research community. This is mainly achieved by scientific publications, talks at academic and industry venues, in-person participation at research workshops and conferences, organization of workshops, involvement in Technical Program Committees of workshops and conferences, and dissemination in social media such as blog posts and twitter announcements.
- Identification of key application(s) for middlebox cooperation mechanisms and further exploitation of project results from impairment measurements and experimentation by industry, through the industrial partners and the direct collaboration with other organizations.

2 Standardisation

The development and evaluation of middlebox collaboration mechanisms can be considered the core focus of the MAMI project from a standardisation point of view. Especially general principles derived from MAMI's research work in this space directly contribute to current work in the IETF, such as a generalized scheme for in-network state management (see draft-trammell-plus-statefulness) and the use of explicit signaling for in-network devices, and also further influence other standardisation bodies as well. Moreover, results related to transport layer interfaces to enable a more flexible (encrypted) protocol selection, efficient trust fabrics supporting automatically-renewed certificates, and measurements of middlebox interference in today's Internet provide input into to standardization, especially in the IETF and IRTF.

Table 2 lists standardisation documents that have been published or revised with a contribution of the MAMI project in the last year and a half since the last report (now updated up to the revision date of this deliverable in Jan 2018). RFC8095 has already been published as output of the IETF's standardisation effort in the RFC series, and all other documents are work in progress.

Body/Group	Document name	partners	sub. date	exp. date
IETF TAPS	RFC 8095	ETH, UNIABDN	March 17	—
IETF QUIC	draft-kuehlewind-quic-manageability-01	ETH	Oct 17	April 17
IETF QUIC	draft-kuehlewind-quic-applicability-01	ETH	Oct 17	April 17
IETF QUIC	draft-trammell-quic-spin-01	ETH, Nokia	Dec 17	June 18
IETF TAPS	draft-trammell-taps-post-sockets-03	ETH	Oct 17	April 18
IETF TAPS	draft-kuehlewind-taps-crypto-sep-01	ETH	Oct 17	May 18
IETF ACME	draft-ietf-acme-star-02	Nokia, TID	Nov 17	June 18
IETF ACME	draft-sheffer-acme-star-request-01	Nokia, TID	June 17	Dec 17
IETF TLS	draft-mavrogiannopoulos-tls-cid-01	Nokia	Nov 16	May 17
IETF TCPM	draft-ietf-tcpm-accurate-ecn-05	ETH	Nov 17	May 18
IETF TSVWG	draft-fairhurst-tsvwg-transport-encrypt-05	UNIABDN	Dec 17	June 18
IETF TSVWG	draft-you-tsvwg-latency-loss-tradeoff-00	ETH	March 16	Nov 16
IETF TSV	draft-trammell-wire-image-01	ETH	Dec 17	June 18
IETF TSV	draft-trammell-plus-statefulness-04	ETH	May 17	Nov 17
IETF TSV	draft-trammell-plus-spec-01	ETH	March 17	Sep 17
IETF TSV	draft-trammell-plus-abstract-mech-00	ETH	April 17	Sep 17
IRTF PANRG	draft-trammell-panrg-questions-02	ETH	Dec 17	June 18
IAB	draft-trammell-privsec-defeating-tcpip-meta-00	ETH	July 16	Jan 17
ETSI CYBER	DTS/CYBER-0027-1 (ETSI)	TID	Jan 17	—

Table 1: Standardisation documents: RFC8095 and work in progress.

2.1 Middlebox Collaboration Mechanisms

These mechanisms, commonly referred in the original MAMI proposal as Middlebox Cooperation Protocol (MCP), are intended to address one of the roughest tussles in the network technology landscape between the ubiquitous deployment of (end-to-end) encryption and ex-

plicit signaling to in-network elements. Arguments in this contention are connected with Internet sustainability and viability of management of a complex interconnected network as well as the application of the original Internet principles around end-to-end interactions and network neutrality on a much different network from the one originally considered when these principles were formulated.

The project has been very active in promoting the idea of mechanisms able to support the collaboration of endpoints and network-hosted elements to enhance network performance and guaranteeing operational properties. Here, work on Path Layer UDP Substrate (PLUS) in the IETF has evolved from the original Substrate Protocol for User Datagrams (SPUD) idea co-developed with the MAMI project proposal. MAMI partners proposed the PLUS Birds of a Feather (BoF) session at IETF 96 in Berlin in July 2016. Despite the support of many of the most active members of the community working on Internet stack evolution, a PLUS Working Group (WG) was not created. Given the strong contention in this space, the project decided to not spend further resources on activities that only aim at bringing PLUS as one concrete protocol for explicit middlebox cooperation into standardization. However, with the creation of the IETF QUIC WG and rapid progress in development and deployment of this new, encrypted, UDP-encapsulated transport protocol, the project is following a different strategy by making contributions to those IETF activities that are focused on Internet stack evolution and thereby making the case for incorporating middlebox collaboration mechanisms developed by the project, in particular:

- Project participants are the editors of two new working group documents[1] on the applicability and the manageability of QUIC. Further the project also works on incorporating the principles of explicit rather than implicit signaling, as well as explicit passive measurability, as elaborated in PLUS, into QUIC via board participation in the working group and a respective QUIC design team that was focus on network expose of RTT information (see also draft-trammell-quic-spin).
- The transport-independent state machine envisioned by PLUS[2] has been presented within the IETF's transport area meeting, with the intend to publish this document as an individual submission as part of the IETF stream of the RFC series, providing background for future work on in-network flow state management of new protocols incl. QUIC.

Beside the IETF, other standards organizations are considering the standardisation of mechanisms for the collaboration of network-hosted middleboxes and communication endpoints, especially from the point of view of providing security services. In particular, the European Telecommunications Standards Institute (ETSI) Technical Committee (TC) CYBER (on cybersecurity) is considering the features of what they exactly term a "Middlebox Cooperation Protocol"' in the recently approved work-item DTS/CYBER-0027. Further, the Institute of Electrical and Electronics Engineers (IEEE) Encrypted Traffic Inspection (ETI) WG is considering mechanisms for establishing trust on middleboxes dealing with encrypted traffic. The MAMI team is monitoring the evolution of these activities and, given their current status, making some initial contributions based on the project results to define their scope.

Finally, the project is collaborating within the GSMA Internet WG in the realization of experiments to evaluate the impact of applying LoLa (Loss vs Latency) classification schemes to traffic management in mobile networks a one example of an end-point provided signal for network

[1] see `https://github.com/quicwg/ops-drafts` for work in progress
[2] `https://tools.ietf.org/html/draft-trammell-plus-statefulness`

enhancements. This collaboration targets in a public report and the availability of open-source software to obtain additional evidence from independent experiments.

2.2 Additional, Related Standardisation Activities

The project's contributions to the IETF to foster the adoption of middleware collaboration mechanisms are paired with the proposed IRTF Path Aware Networking (PAN) Research Group (RG), which aims to support research in bringing path awareness to transport and application layer protocols, and to bring results of this research to the attention of the Internet engineering and protocol design community, focusing on collection and measurement of path characteristics as well as path selection as it can be provided by the project's work on a Flexible Transport Layer (FTL) in support of the path layer mechanisms that are part of the project proposal on middlebox collaboration mechanisms.

The MAMI project is also contributing to the consolidation of a new application interface to the Internet transport protocol stack, characterizing transport services in the first Request for Comments (RFC) already published during the project lifetime (RFC 8095), and proposing a new, message-based, asynchronous Application Programming Inferface (API) for interacting with these transport services[3] enabling more flexible protocol selection and stack composition supporting faster and more dynamic protocol evolution. These contributions have been made through the IETF Transport Services (TAPS) WG. In addition, some initial work has been proposed in the IETF Transport Layer Security (TLS) WG to decouple security associations from transport protocol instances.

There have been contributions as well to create mechanisms for trust management that support a broader set of the scenarios that could be enabled by a wide deployment of network-endpoint collaboration. In particular, the MAMI project has been working within the IETF Automated Certificate Management Environment (ACME) WG to define mechanisms supporting key and certificate management able to control trust link delegation to unattended devices or processes. These scenarios are especially relevant for certain kind of middleboxes (those dealing with caching, for example) and to support the application of middlebox collaboration mechanisms in Network Function Virtualisation (NFV) environments. This application has already been brought to the ETSI NFV Security WG.

Measurement and middlebox characterisation are further standardisation targets in work by the project team. The IRTF Measurement and Analysis for Protocols (MAP) RG, created on the project's initiative and co-chaired by one project participant, is committed to provide research evidence on Internet measurement to inform protocol engineering and practice in the IETF. Besides this, specific considerations on the need to incorporate measurability considerations in protocol design in the face of increased deployment of encryption on all layers to support future Internet evolution have been brought to the IETF TSV WG. Furthermore, the project's work on middlebox characterization is in the process of being combined with a model based on atomic capabilities, first proposed within the IETF Interface to Network Security Functions (I2NSF) WG and currently restricted to security-related functionality, with the aim to provide a flexible standard for middlebox classification.

[3] https://tools.ietf.org/html/draft-trammell-taps-post-sockets/

3 Industrial and Academic Exploitation

This section describes the exploitation steps taken to date by each partner, organized by partner type (industrial, academic). Given this is an intermediate report, these descriptions also include the exploitation plans going forward.

3.1 Industrial Exploitation

3.1.1 Telefónica I+D (TID)

TID is working to apply the MAMI results to network services provided by Telefonica Business Units along two main directions: (a) utilizing and contributing to measurement data in the MAMI PTO; (b) applying the middlebox cooperation mechanisms to NFV and cloud-based services in the Telefonica portfolio, as further described below.

The collaboration with industry associations like GSMA is an important argument for these activities, and TID keeps fostering cross-collaboration between the project and these industry associations, and leveraging dissemination activities at industrial events and social media to increase internal impact in Telefonica Business Units as well as external impact in cooperation with other industry partners.

MAMI PTO and measurement data

TID is continuously collaborating with different Telefonica Business Units on requests for trustworthy and independent data sources to evaluate the network impact of the currently on-going deployment of pervasive end-to-end encryption resulting in a potential need for changes in the currently applied network management techniques and the nature of the services offered by these business units. Therefore, TID is building awareness about the MAMI PTO as a source of trustworthy measurement data that can influence the evolution of Telefonica's plans for its next-generation integrated telco cloud and the services hosted by it. In addition, TID fosters also their contribution to the PTO with its own measurement campaigns, as well as future consolidation of the measurement data beyond the project lifetime. The work in the http://isthewebhttp2yet.com site, started as an internal observatory of HTTP2 adoption and now part of the MAMI PTO datasets, is being used as an exemplar case of the applicability of the PTO to Telefonica business intelligence sources.

Application of middlebox cooperation mechanisms

TID is further working on the application of these mechanisms in Telefonica's network infrastructures in three work areas, as described in the previous report:

1. UNICA is an integrated cloud infrastructure intended to support a large variety of network elements and applications, including management tools and NFV-based services with the goal of enhancing software-based service provisioning, simplifying network management tasks, and taking advantage of NFV to address network service personalization. TID investigates how the middlebox cooperation can support NFV-based services, e.g. utilizing the tracing Path Communication Function (PCF)

defined by PLUS to ensure that certain network-functions in a function chain have been applied.

2. Niji is a service provided by Telefonica for anonymisation and optimisation of web access, as a commercial offering onto their 3G/4G networks. The service differentiation function can be utilized in Niji to improve user experience and facilitate the evolution of the service, especially facing the current trends around evolution of new, encrypted transport protocols as well as other applications of encryption. Since Niji will eventually be hosted on the UNICA infrastructure, there is a clear opportunity for aligning both exploitation efforts.
3. Telefonica's Virtualized Home Environment (VHE), applying NFV principles to provide network services to residential and SME customers, aims to lower operational costs and supporting much faster updates of protocols and services. All current home environments run several middleboxes (NATs, firewalls, parental control sytems). TID is working on developing further signalling to support these functions in state management and providing intents.

TID is directly collaborating with Nokia to run a Loss-Latency tradeoff marking (LoLa) experiment at the 5TONIC 5G lab[1]. The experiment is planned to run in April 2018. More details on this, as presented to the 5TONIC Steering Board, are provided in the following section.

As a result of this and other experiments planned for the next months as well as discussions at the Industry workshop planned for March 2018 (co-located with the IETF-101 in London) together with other industry, the project plans to publish a white paper on management of encrypted traffic, and distribute it internally within the industrial partners of the project, especially Telefonica, and externally to foster adoption of middlebox cooperation mechanisms in new and existing protocols (likely as a contribution to GSMA). The whitepaper is planned for September 2018, and will include discussions and experimentation results of cooperative signaling mechanisms (trust-but-verify), as originally proposed by PLUS, as an alternative to the use of DPI in mobile networks, as well as further work on cooperation mechanisms that require a trust relationship between network and endpoints. However, given the lack of standardization of the PLUS protocol at this point of time and the respective strategy change as explained above as well as the overall time frame of the project, any direct exploitation of MAMI results can only follow after the end of the project where the whitepaper provides a basis for further dissemination by summarizing our finding and discussions in standardization and other industry forums.

3.1.2 Nokia

Nokia can exploit the results of MAMI in many different sectors of its product portfolio including, but not limited to, mobile edge and core, Software Defined Networking (SDN), and IP video.

In particular, Nokia investigates to integrate MAMI results into the Velocix product line (Content Delivery Network (CDN), multicast Adaptive Bit Rate (mABR) and Personalisation Platform) to provide enhanced cooperation with the mobile network to provide better Quality of Experience (QoE) and expand the number of adaptation/personalisation functionality for Over-The-Top (OTT) video delivery. To enable such services Nokia plans to change the way encrypted traffic negotiation is handled at edge locations of its CDN and mABR products, based on the

[1] https://www.5tonic.org

use of the technology proposed for standardisation in ACME, Short Term Automatically Renewed (STAR) certificates. This product line is planned to be demonstrated at the 101 IETF Hackathon in London (March 2018). Work on use of the Mobile Throughput Guidance (MTG) signal by the TCP congestion controller on the edge cache is ongoing with the University of Aberdeen.

Further, the results related to the connection identifier (draft-ietf-tls-dtls-connection-id) for TLS and Datagram Transport Layer Security (DTLS) will be incorporated into the IMPACT Internet of Things (IoT) product line.

Moreover, Nokia is chairing the Content Classification project in the GSM Association (GSMA) focusing on defining and executing the “1-bit Experiment” (see Internet Architecture Board (IAB) MarNEW workshop and IETF Alternatives to Content Classification for Operator Resource Deployment (ACCORD) BoF) in order to provide low latency support by explicit path signaling. Currently, Nokia is running initial experiments to verify (or refute) the hypothesis that explicit packet markings are beneficial to QoE as well as to evaluate energy and scheduling efficiency in the radio segment (including eNodeB and Terminal Equipment (TE)).

As mentioned in the previous section, a concrete experiment on this matter will be run at the 5TONIC 5G testbed, in collaboration with TID. The experiment has been approved by the 5TONIC Steering Board, and is planned for April 2018. The experiment intends to validate the usage of LoLa markings on LTE in situations of near-congestion. The goal is to understand whether it is beneficial to harmonize LoLa signalling with the Quality of Service (QoS) model defined in LTE and, if so, to quantify its impact in comparison to the status quo (default bearer) and 0-bit, non-cooperative schemes (e.g. AQM).

3.2 Academic Exploitation

3.2.1 ETH Zurich

ETH Zurich has continuously, since the beginning of the project, involved students in the research work conducted in the project on both transport protocol design and evaluation as well as middlebox measurement data collection, analysis, and preservation. Since the last report one additional semester thesis (3 month) on continuous measurements has started and concluded and two new master theses (6 month) on low latency evaluation and integration of tracing facilities into PATHspider are on-going. Further, a doctoral student is now working on the project’s middlebox implementation evaluating mechanisms for explicit protocol support of in-network passive measurement.

Moreover, based on the work in the MAMI project on flexible transport stack composition and a new API, the Networked Systems Group (NSG) is extending its collaboration with other groups in ETH, as well as research groups and industry partners outside of the project ensuring future exploitation of project results in standardisation or potential follow-up projects.

3.2.2 ZHAW

MAMI is important to the security group at ZHAW precisely because its focus is not primarily on security. The group is learning about the tradeoffs one has to make when security is important,

but not the main goal of a design, as it would be with PLUS or QUIC. The proposed PLUS protocol is not designed with security as an own layer but as a component that can support the protocol stack on different layers; QUIC incorporates security within the security but is also designed modularly such that the security handshake protocol could be easily changed. Assembling expertise in the advantages, risks, and security implications of this approach will form an important part of ZHAW's future research outlook that can be applied to future excerises in protocol design and security analysis of network protocols.

Therefore, ZHAW has been involving students in MAMI by offering a number of Bachelor and project theses (depending on the student's involvement). The theses are focusing on work in Linux kernel development by acquiring expertise in equipping a modern Linux kernel with new networking protocols; using state-of-the-art libraries to create client-side visualisations from the observatory, either as a general framework or as a concrete visualisation project; and further work on the observatory, together with ETH.

In teaching, PLUS will serve as an example of a protocol that is being deployed with full knowledge of nation-state adversaries, and the attendant need for security and risk analysis, so that protocol users have a realistic sense of what kind of security they can expect. We are already using PLUS as an example of the tradeoffs one can expect when doing security work when the primary focus is not security: on the one hand, one wants to offer as little metadata as possible, in order to prevent an adversary from learning too much. On the other hand, some metadata is needed to keep the infrastructure operating at sufficient profitability levels to keep it going.

3.2.3 University of Aberdeen

MAMI is an important part of the University of Aberdeen research portfolio. The UoA values the experience and understanding of best current practice in engineering that have resulted from participation in this project. It plans to promote the results of the MAMI project as a part of its research portfolio. In this respect, the project is expected to continue to support the academic outputs through publication in journals and research papers. UoA will continue to use outcomes of the MAMI measurement work to support teaching and postgraduate education in Internet Engineering, e.g. through lectures and workshops, and by participation to summer schools.

The concepts developed are expected to stimulate future research in related areas. It is already providing new opportunities to develop closer relationships with key industry players where appropriate. UoA will investigate future R&D funding calls to continue development of the new methods introduced in MAMI. At this stage it is difficult to assess what additional funding might be required (if any). This depends on the data collected in measurements and the final research outcomes of the project.

UoA sees standardisation as a powerful mean to boost the exploitation of the research results of the MAMI project. Prior to standards adoption new ideas need to be made known to the community and discussed. Socialization of new research solutions is hard within the lifetime of an H2020 project, particularly for changes that challenge an existing system architecture. However, the UoA has a track record of contributing to the IETF, particularly on the transport protocols, and anticipates that work started in the project will influence and contribute to further standardisation in the area of Internet transport — throughout the TAPS, QUIC and TSVWG working groups, with standardisation work likely extending beyond the duration of the current project.

3.2.4 Simula Research Laboratory

SRL plans to exploit MAMI's results in three ways. First, participation in the project allows it to expand its network of research partners in Europe. Second, results and experience coming from MAMI will be leveraged in future project proposals targeting either European or national funding agencies. Finally, SRL also plans to contribute to the PhD summer school that will be organised later in the project.

3.2.5 University of Liege

As a university, ULg leverages the knowledge and experience acquired within MAMI in advanced networking courses. In particular, research activities on measuring middleboxes interference and modeling those middleboxes are included in a "Network and Monitoring Measurements" and "Computer Security" courses given to Master Students.

In addition, Master theses and research projects are currently being proposed to students for next academic year (starting in September 2017).

4 Dissemination and Communication

Besides other dissemination communication actions as listed below, the MAMI project continuously participates in EC clustering initiatives, such as the FIRE Dissemination Working Group (DWG). As a supplement of this dissemination efforts within the EU research landscape, the project has further developed cooperative relationships with related EC-funded projects during the last year.

From the beginning, SRL provided the primary point of contact with MONROE, and we are now also working on joint dissemination with PATHspider as one available measurement tool on the MONROE platform. Both projects held a common workshop in June 2016 (see below). In addition, UNIABDN, an associated experimenter in the MONROE project, is performing additional path measurements that provides input to the PTO.

Further, we also developed a closer relationship with the EU-H2020 NEAT project: a small invitation-only workshop with NEAT participants was held in February 2017 in Zurich (also see below), and MAMI participants have served on the TPC of the Future of Internet Transport (FIT) workshop at the IFIP Networking conference which has been organized by the NEAT project.

4.1 Communication Actions

MAMI's communication actions are focused on social media through a webpage blog and twitter as well as in-person dissemination at research and industry events (distributing stickers), including the organization of own research workshops. Both activities are further described below.

4.1.1 MAMI Web Sites

The MAMI website `https://mami-project.eu/` is continuously updated with information on publications, standardisation efforts, events, and a lively blog used to disseminate MAMI research results and activities. Currently there are 24 blog posts in total, with 16 new posts since the last report. The posts contain reports from standardisation events, workshops, project meeting as well as measurements reports and comments on on-going research or software development.

Since May 2016 the MAMI PTO is also online as a subdomain (`https://observatory.mami-project.eu/`). Further, MAMI maintains an own webpages for PATHspider (`https://pathspider.net/`).

4.1.2 Twitter

The MAMI twitter account (@mamiproject) is actively maintained to announce MAMI work and publications as well as blog posts. As of 29 June 2017, the channel has currently 135 followers and a total of 233 tweets since June 2016.

4.1.3 Industry Events

The project problem statement, its goals, and early results in connection with the Software Network concepts were presented by TID at last year's SDN NFV World Congress in The Hague (`https://www.layer123.com/sdn`). The slides for this presentation are available at `https://github.com/mami-project/roadshows/tree/master/SDNWorldCongress2016`.

4.1.4 Workshops

The project has organized a joint workshop with the EU-H2020 MONROE project on Mobile Network Measurements (MNM) in conjunction with TMA Conference 2017 on June 20, 2017, in Dublin/Maynooth, Ireland (`http://tma.ifip.org/workshops/mnm17-workshop/`). The workshop received 16 paper contributions, and 10 6-page papers were selected by the TPC, consisting of participants from both projects as well as MAMI EAB members, for presentation at the workshop. The workshop was organized in three technical sessions and supplemented by a keynote on "From packets to knowledge: applying data science approaches to traffic measurement" held by Marco Mellia, Politecnico di Torino, Italy. With a total of 18 registered participants, and a couple of visitors from the parallel workshops, the workshop provided lively discussion and a good opportunity to make people aware of MAMI's measurement efforts, raising interest in a focused community of MONROE users as well as other researchers working on Internet measurements in academia and industry.

Further, the project organized a small and focused workshop on February 13, 2017 in Zurich with 12 in-person and 2 remote participants for discussion of a new sockets API, leading to input provided to the IETF TAPS WG. The workshop was on invitation only, focusing on the exchange of ideas and development of a common approach, with a large number of the participants that are working on similar approaches in the EU-H2020 NEAT project.

4.2 Software

The following subsections list new and on-going software-related activities since the last report.

4.2.1 GitHub

The MAMI project makes all software efforts openly avaialble on GitHub (`https://github.com/mami-project/`). Table 2 lists all active repositories in the last year as well as the MAMI partners that are currently working on the respective software or study.

Table 2: List of public MAMI software and documentation repositories in github

Group	Repository	Description	Partner(s)
General	roadshows	Public slideware for the H2020-ICT-688421 MAMI project	All

Table 2: List of public MAMI software and documentation repositories in github (continued)

Group	Repository	Description	Partner(s)
Drafts	draft-kuehlewind-quic-appman	Applicability and Management of the QUIC Transport Protocol (Internet-Draft)	ETHZ
	draft-trammell-post-sockets	Post Sockets. An Abstract Programming Interface for the Transport Layer	ETHZ
	draft-kuehlewind-crypto-sep	Description of an architecture separating persistent cryptographic and ephemeral per-path transport state	ETHZ
	draft-pauly-transport-security	Survey of security features in Internet protocols	ETHZ, extern
	draft-trammell-plus-statefulness	Transport-Independent Firewall State Management using PLUS	ETHZ
	draft-trammell-plus-spec	Experimental protocol specification for the Path Layer UDP Substrate	ETHZ
	draft-trammell-plus-abstract-mech	Abstract Mechanisms for a Cooperative Path Layer under Endpoint Control	ETHZ
	draft-kuehlewind-plus-problem-statement	Problem Statement and Initial Use Cases for a Path Layer UDP Substrate (PLUS)	ETHZ
PTO	pto3	Path Transparency Observatory Storage, Query, and Analysis API, version 3	ETHZ, ZHAW
	pto3-ecn	ECN analyzers for Path Transparency Observatory (PAPI v3)	ETHZ
	pto-web	Path Transparency Observatory (PTO) web frontend	ZHAW
	pto-postgres	PostgreSQL backend for Path Transparency Observatory and associated utilities (version 2 obsoleted by pto3)	ETHZ, ZHAW
	pto-core	The PTO core programs (version 1 obsoleted by pto-postgress)	ETHZ, ZHAW
	observatory-upload	Upload handling for the MAMI observatory (version 1 obsoleted by pto3)	ZHAW
	pto-util	Utilities for managing the Path Transparency Observatory (version 1 obsoleted by pto3)	ETHZ
	pto-ui	Web user interface for the Path Transparency Observatory (version 1 obsoleted by pto3-web)	ETHZ, ZHAW
	pto-ecn-base	Analyser module for PATHspider ECN for basic analysis of flow-based observations (version 1 obsoleted by pto3-ecn)	ETHZ
	pto-ecn-path-dependancy	Analyser module for PATHspider ECN path dependancy (version 1)	ETHZ
	pto-ecn-super	ECN path-dependency analyzer for pto-core (version 1)	ETHZ

Table 2: List of public MAMI software and documentation repositories in github (continued)

Group	Repository	Description	Partner(s)
PATH-spider	pathspider	Tool for A/B testing of path transparency to certain features in the Internet	ETHZ, UNI-ABDN
	pathspider-example	A starting point for PATHspider plugin development	UNIABDN
	autospider-salt	Salt provisioning for automated runs of PathSpider (or other measurement tools)	ETHZ
	pathspider-monroe	Docker image for PATHspider on MONROE	UNIABDN, SRL
	pathspider-monroe-template	Template MONROE Experiment using PATHspider	SRL, UNI-ABDN
	python-libtrace	A Cpython module to make the libtrace library available to Python2 and/or Python3	ETHZ, UNI-ABDN
	targets	Lists of public targets for active measurement studies	ETHZ, UNI-ABDN
tools	tracebox	Tracebox over Scamper	ULg
	copycat	Network/Transport Protocol Comparison Tool (UDP vs TCP, Custom vs TCP, IPv4 vs IPv6)	ULg, ETHZ
	udpdiff	Scripts and data for differential UDP/TCP performance measurements	ETHZ, ULg
	revelio	Revelio NAT detection tool	SRL
	h2-measurements	Measure HTTP2 deployments and availability	TID
	mplane-sdk	mPlane protocol software development kit	ETHZ, ULg, UNI-ABDN, ZHAW
	mplane-protocol	mPlane Architecture and Protocol Specification (v2, Internet-Draft)	ETHZ
data	ecn-conspiracy	Scripts and data for measuring ECN negotiation and connectivity dependency	ETHZ
	must-go-faster	Data and analysis for "Must Go Faster: measuring the deployability of protocols supporting low latency"	ETHZ
encrypt.	lurk	ACME STAR implementation	Nokia, TID

Table 2: List of public MAMI software and documentation repositories in github (continued)

Group	Repository	Description	Partner(s)
	KeyServer	Key Server that implements the TLS Session Key Interface (SKI) defined in draft-cairns-tls-session-key-interface	TID
Exp./ Impl.	one-bit-experiment	Experimental framework to compare the effect of cooperative vs non-cooperative schemes on QoE	Nokia, TID
	vpp-plus	VPP-based PLUS middlebox implementation	ETHZ
	postsocket	Go implementation of PostSockets over various transports	ETHZ

4.2.2 Software Distribution Systems

MAMI also attempts to distribute measurement tools developed during the project via packages in software distribution systems, for example the Debian Operating System[1] and the Python Package Index[2].

The PATHspider releases 1.0.0 and 1.0.1, released 21st October 2016 and 4th November 2016 respectively, are both available for installation from PyPI[3]. PATHspider 1.0.1 was included in the release of the latest stable version of the Debian operating system[4]. Since then the Debian Project has had a freeze on accepting new contributions which ended on the June 17th 2017. Now that contributions are accepted again we are currently planning for the next update of the PATHspider codebase and its dependencies to be released in in the Debian Project repositories soon to the current reflect development status since the last update.

4.2.3 IETF Hackathon

Partners of the MAMI project regularly participate in IETF Hackathons to socialise ideas and code related to MAMI activities. Nokia brought TLS CID to IETF 98 and the one-bit experiment and ACME STAR to IETF 99 and IETF 100 as well as has scheduled a demonstration of the Velocix product line at the 101 IETF Hackathon in London (March 2018).

4.3 Publications and Talks

This section provides an overview of talks and scientific papers that are newly published or already accepted but not published yet since the last report in June 2016 (see project webpage for the full list).

[1] `https://www.debian.org`
[2] `https://pypi.python.org/`
[3] https://pypi.python.org/pypi/pathspider
[4] https://packages.debian.org/source/stable/pathspider

4.3.1 Talks Given

There is only one additional talk since the last report, as listed in table 3. In this phase of the project, dissemination now is focused on paper publication that of course also results in participation and presentation of MAMI goals and results at conferences, workshops, and industry events (see below).

Table 3: List of MAMI talks

Venue	Date	Title	Speaker
SDN & NFV World Congress	12.10.16	**The MAMI Project and the NFV Way to Internet Path Transparency**	D. Lopez (TID)
Introduction to the MAMI problem statement, approach, and early results, including a discussion on the role to be played by NFV in achieving the independent measurement and network-endpoint collaboration. Slides available at `https://github.com/mami-project/roadshows/blob/master/SDNWorldCongress2016`			

4.3.2 Conference, Workshop, and Journal Papers

Table 4 lists the published or accepted contributions to workshops, conferences and journals since the last dissemination report in June 2016.

Table 4: List of MAMI publications

Venue	Date	Title	Authors
arXiv:1612.07816	22.12.16	**Using UDP for Internet Transport Evolution** (report - not peer-reviewed)	K. Edeline (ULg), M. Kühlewind (ETH), B. Trammell (ETH), E. Aben (RIPE), B. Donnet (ULg)
The increasing use of middleboxes (e.g., NATs, firewalls) in the Internet has made it harder and harder to deploy new transport or higher layer protocols, or even extensions to existing ones. Current work to address this Internet transport ossification has led to renewed interest in UDP as an encapsulation for making novel transport protocols deployable in the Internet. Examples include Google's QUIC and the WebRTC data channel. The common assumption made by these approaches is that encapsulation over UDP works in the present Internet. This paper presents a measurement study to examine this assumption, and provides guidance for protocol design based on our measurements. The key question is "can we run new transport protocols for the Internet over UDP?" We find that the answer is largely "yes": UDP works on most networks, and impairments are generally confined to access networks. This allows relatively simple fallback strategies to work around it. Our answer is based on a twofold methodology. First, we use the RIPE Atlas platform to basically check UDP connectivity and first-packet latency. Second, we deploy copycat, a new tool for comparing TCP loss, latency, and throughput with UDP by generating TCP-shaped traffic with UDP headers.			

Table 4: List of MAMI publications (continued)

Venue	Date	Title	Authors
IEEE Internet Computing	March 2017	**Innovating Transport with QUIC: Design Approaches and Research Challenges** (journal)	Y. Cui (Tsinghua Uni), T. Li (Tsinghua Uni), C. Liu (Tsinghua Uni), X. Wang (Northeastern Uni) M. Kühlewind (ETH)
QUIC UDP Internet Connections (QUIC) is a new transport protocol that provides low-latency communication, security, and rapid deployment. QUIC has begun its standardisation process with strong interest in the IETF community. This article introduces QUIC?s features and discusses its challenges.			
arXiv:1704.01296	5.4.17	**Tracking the Big NAT across Europe and the U.S.** (report - not peer-reviewed)	A. N. Mandalari (UC3M), A. Lutu (SRL), A. Dhamdhere (CAIDA), M. Bagnulo (UC3M), KC Claffy (Caida)
Carrier Grade NAT (CGN) mechanisms enable ISPs to share a single IPv4 address across multiple customers, thus offering an immediate solution to the IPv4 address scarcity problem. In this paper, we perform a large scale active measurement campaign to detect CGNs in fixed broadband networks using NAT Revelio, a tool we have developed and validated. Revelio enables us to actively determine from within residential networks the type of upstream network address translation, namely NAT at the home gateway (customer-grade NAT) or NAT in the ISP (Carrier Grade NAT). We demonstrate the generality of the methodology by deploying Revelio in the FCC Measuring Broadband America testbed operated by SamKnows and also in the RIPE Atlas testbed. We enhance Revelio to actively discover from within any home network the type of upstream NAT configuration (i.e., simple home NAT or Carrier Grade NAT). We ran an active large-scale measurement study of CGN usage from 5,121 measurement vantage points within over 60 different ISPs operating in Europe and the United States. We found that 10% of the ISPs we tested have some form of CGN deployment. We validate our results with four ISPs at the IP level and, reported to the ground truth we collected, we conclude that Revelio was 100% accurate in determining the upstream NAT configuration for all the corresponding lines. To the best of our knowledge, this represents the largest active measurement study of (confirmed) CGN deployments at the IP level in fixed broadband networks to date.			
Computer Communication Review	April 2017	**Principles for Measurability in Protocol Design** (journal)	M. Allman (ICIR), R. Beverly (NPS), B. Trammell (ETH)
Measurement has become fundamental to the operation of networks and at-scale services, wether for management, security, diagnostics, optimization, or simply enhancing our collective understanding of the Internet as a complex system. Further, measurements are useful as points of view from end hosts to enterprise networks and data centers to the wide area Internet. We observe that many measurements are decoupled from the protocols and applications they are designed to illuminate. Worse, current measurement practice often involves the exploitation of side-effects and unintended features of the network; or, in other words, the artful piling of hacks atop one another. This state of affairs is a direct result of the relative paucity of diagnostic and measurement capabilities built into today's network stack. Given our modern dependence on ubiquitous measurement, we propose measurability as an explicit low-level goal of current protocol design, and argue that measurements should be available to all network protocols throughout the stack. We seek to generalize the idea of measurement within protocols, e.g., the way in which TCP relies on measurement to drive its end-to-end behavior. Rhetorically, we pose the question: what if the stack had been built with measurability and diagnostic support in mind? We start from a set of principles for explicit measurability, and define primitives that, were they supported by the stack, would not only provide a solid foundation for protocol design going forward, but also reduce the cost and increase the accuracy of measuring the network.			

Table 4: List of MAMI publications (continued)

Venue	Date	Title	Authors
FIT Workshop	12.6.2017	**Post Sockets: Towards an Evolvable Network Transport Interface**	M. Kühlewind (ETH), C.Perkins (University of Glasgow), B. Trammell (ETH)
The traditional Sockets API is showing its age, and no longer provides effective support for modern networked applications. This has led to a proliferation of non-standard extensions, alternative APIs, and workarounds that enable new features and allow applications to make good use of the network, but are difficult to use, and require expert knowledge that is not widespread. In this paper, we present Post Sockets, a proposed new standard network API, that is designed to support modern network transport protocols and features, while raising the level of abstraction and enhancing usability. Specifically, Post Sockets aims to give portable applications the ability to use a clear, messages based, interface to multi-path and multi- stream transports, rendezvous and connection racing, and fast connection reestablishment.			
EUCNC 2017	12–15.6.17	**Measurement-based Protocol Design** (poster)	G. Fairhurst (UNIABDN), M. Kühlewind (ETH), D. Lopez (TID)
The increasing public concerns about the interfer- ence of Internet traffic have led to a rapidly expanding deploy- ment of encryption to protect end-user privacy, in protocols like QUIC. At the same time, network operators and access providers, especially in mobile networks, have come to rely on the in- network functionality provided by middleboxes both to enhance performance and support network operations. This presents a need for architectural changes and new approaches to the way network transport protocols are designed. This paper explores the opportunities to use an experimentally-driven measurement-based approach to facilitate this network architecture evolution.			
MNM'17 workshop	20.6.17	**Hic Sunt NATs: Uncovering Address Translation with a Smart Traceroute**	R. Zullo (U. Napoli), A. Pescapé (U. Napoli), K. Edeline (ULg), B. Donnet (ULg)
Middleboxes are pervasive in today's Internet as they are deployed for an increasing number of reasons. An example is the network address translation (NAT), one of the first task to be performed to cope with the lack of IPv4 addresses. Recently the landscape for NATs has become even more crowded, especially in mobile networks, mainly due to the impossibility of IPv6 to be a large-scale solution to addressing issues. In this paper, we present a novel methodology for detecting NATs embodied in Mobile Tracebox, a measurement tool for Android smart devices that detects a wide range of middleboxes. It analyzes ICMP `time_exceeded` messages received during `traceroute` and points at IP and transport checksum inconsistencies in the embedded packets to uncover address translation along a path.			

Table 4: List of MAMI publications (continued)

Venue	Date	Title	Authors
MNM'17 workshop	20.6.17	**Performing path transparency measurements with PATHspider from the mobile edge**	I. R. Learmonth (UoA), A. Lutu (SRL), G. Fairhurst (UoA), D. Ros (SRL), O. Alay (SRL)
Network operators and equipment vendors can hesitate to deploy network protocol innovations in fear of breaking connectivity for end users. To assess the potential for evolution of the protocol stack, it is important to know the existing network impairments and opportunities to work around the impairments. While classical network measurement tools often focus on absolute performance values, PATHspider is an extensible framework for performing and analyzing A/B testing between two different protocols or different protocol extensions. It thus enables controlled experiments in search of protocol-dependent connectivity problems, and to identify differential treatment. This paper presents how PATHspider can be instrumented to assess path transparency over commercial mobile networks, using the MONROE platform. We provide here proof-of-concept results from measurements in a UK commercial mobile network, and lay out our future measurement plans for PATHspider using the MONROE testbed in Europe.			
ANRW'17	15.7.17	`copycat`**: Testing Differential Treatment of New Transport Protocols in the Wild**	K. Edeline (ULg), M. Kühlewind (ETH), B. Trammell (ETH), B. Donnet (ULg)
Recent years have seen the development of multiple transport solutions to address the ossification of TCP in the Internet, and to ease transport-layer extensibility and deployability. Recent approaches, such as PLUS and Google's QUIC, introduce an upper transport layer atop UDP; their deployment therefore relies on UDP not being disadvantaged with respect to TCP by the Internet. This paper introduces `copycat`, a generic transport protocol testing tool that highlights differential treatment by the path in terms of connectivity and QoS between TCP and a non-TCP transport protocol. `copycat` generates TCP-shaped traffic with custom headers, and compares its performance in terms of loss and delay with TCP. We present a proof-of-concept case study (UDP vs. TCP) in order to answer questions about the deployability of current transport evolution approaches, and demonstrate the extent of `copycat`'s capabilities and possible applications. While the vast majority of UDP impairments are found to be access-network linked, and subtle impairment is rare, middleboxes might adapt to new protocols that would then perform differently in the wild compared to early deployments or controlled environment testing.			

Table 4: List of MAMI publications (continued)

Venue	Date	Title	Authors
ANRW'17	15.7.17	**Tracking transport-layer evolution with PATHspider**	Brian Trammell (ETH), Mirja Kühlewind (ETH), Piet De Vaere (ETH), Iain R. Learmonth (UoA) and Gorry Fairhurst (UoA)
The ossification of the Internet protocol stack, due in large part to mangling of packets by middleboxes, has led to a relatively slow rate of change in today?s Internet. We have developed the PATHspider active Internet measurement tool which performs one- sided measurements of a variety of transport-layer features and extensions, to investigate these impairments to protocol evolution along an Internet path. Data collected with PATHspider can be used both to determine the degree of support for these features, as well as to detect connectivity issues caused by attempting to use them. The wider aim of this effort is to provide quantifiable input to protocol design and deployment choices that can be based on the level of impairment present in the Internet. This paper details PATHspider?s design, and applies it to trace the evolution of deployment of two extensions to TCP, Explicit Congestion Notification (ECN) and the newer TCP Fast Open (TFO); as well as the degree of interference with the Differentiated Services Code Point (DSCP) carried in the IP header. Our ECN results, in particular, expand on a long-term study beginning in 2012, and show continued linear adoption of ECN. Automating PATHspider measurements has allowed us to collect far more data than in previous campaigns, allowing us to better distinguish ECN-linked connectivity failures from transient effects. Interestingly, we observe a correlation between ECN-linked connectivity failure in the core of the network with the presence of large-scale, heterogeneous Internet censorship infrastructure.			
SIGCOMM'17 Reproducibility Workshop	25.8.2017	**Challenges with Reproducibility** (position)	V. Bajpai (TUM), M. Kühlewind (ETH), J. Ott (TUM), J. Schönwälder (Uni Bremen), A. Sperotto (Uni Twente), B. Trammell (ETH)
The Computer Science (CS) culture is gentle to accepting papers that are non-reproducible as long as they appear plausible. In this paper, we discuss some of the challenges with reproducibility and a set of recommendations that we as a community can undertake to initiate a cultural change.			
ITC'17	4–8.9.17	**A First Look at the Prevalence and Persistence of Middleboxes in the Wild**	K. Edeline (ULg), B. Donnet (ULg)
Recent years have seen an uprise in the development of middleboxes functionalities (CGNATs, proxies, accelerators, etc), participating so in the ossification of the Internet. In parallel, various solutions have been developed to detect or circumvent unwanted middleboxes interferences such as UDP-based middlebox-proof transports (Google's QUIC, PLUS), middlebox-proof extensions to TCP (HICCUPS, TCPcrypt), and middlebox traversal mechanisms (STUN, ICE, PLUS). All those solutions make the assumption of ubiquitous middleboxes. However, a view of their actual deployment in the wild, in IPv4 wired networks, is missing. In particular, knowing how autonomous systems (ASes) deploy middleboxes in terms of prevalence and persistence would provide additional relevant information to Internet topology models. In this paper, we aim at filling this gap. Based on a large-scale measurement campaign, we highlight different characteristics of middlebox deployment within ASes to elicit middleboxes profiles.			

5 Conclusion

This deliverable reports the standardisation, dissemination, and exploitation activities carried out in MAMI in the last year since the last report in June 2016. In this timespan the project has foremost significantly increased its number of publications as well as related and on-going implementation efforts. In addition, dissemination still focuses on standardisation and industry impact with a change in strategy regarding the deployment of middlebox collaboration mechanisms towards participation in established groups and application of MAMI results and derived principles to protocols that are currently under development, instead of the development and standardization of one explicit protocol for middlebox cooperation that works on a shim-layer between network and transport as originally envisioned in the project proposal. With this change in strategy the project has concluded the development of the PLUS protocol as one strawman protocol for explicit middlebox cooperation, modulo any adaptions that might follow based on our work on a reference implementation, and now focuses on experimentation with middlebox collaboration mechanisms that could be applied either to PLUS as well as other protocol that can implement some form of explicit network signaling, such as the use of DSCP, IP/TCP option or new header types in QUIC. Therefore the project's exploitation efforts do also not focus on PLUS directly anymore, given the current lack in standardization hinders endpoint support which is essential for large-scale deployment. However, instead the project supports industry to input their needs into on-going standardization effort which the option of realizing common signal schemes that will be used by a large set of future stateful middlebox with a first focus on network measurements and monitoring elements. In addition, various activities, such as the organization of IRTF research groups and academic workshops as well as a lively reporting on MAMI-related information in social media, further increases the awareness of MAMI work and results for relevant stakeholders.