D7.6 FINAL REPORT

Project[1] Number: H2020-ICT-2014-1-644332
Project Acronym: OpenAIS
Project title: Open Architectures for Intelligent Solid State Lighting Systems

Final Report

Period covered by the report: from 01/01/2015 to 30-06-2018

[1] The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation

Contents

1 Overview of the results and their exploitation and dissemination

1.1 Overview of results

OpenAIS researched user expectations, derived requirements and use cases and created a fully CoAP / IoT based **lighting controls and communication architecture** seamlessly working on all physical internet media. The architecture closes the identified gaps between the existing IoT frameworks and the domain specific requirements from the lighting industry. The architecture has been verified by a full-scale office lighting system, including presence, daylight and user control at a real office space, also including smartphone control through user Apps and an Integration in a standard BMS- System.
The most critical new architecture solutions that OpenAIS designed and introduced to cover the requirements for professional indoor lighting, namely out-of-the-box operation, low latency secure large group control, local control resilience and peak bandwith control in multi-PHY IPv6 based systems, have been proven to work sufficiently well.

The stakeholder and user research identified three main success elements for IP based lighting controls: "**Easy life**", "**increased building value**" and "**building wide ecosystem**". All three include life-cycle aspects that need technological and communication flexibility that allow the adaptation of the system over the deployment lifecycle.

- The request for Easy life asks for open APIs that allows for various Application and User Interface generations, for simplicity in design, implementation and operation and for security measures one can rely on.
- The request for increased building value asks for visible and sustained value of the investment, and for adjustable functionality and related operational expenses according to need during the life cycle. This includes all kind of future cloud-based mining and related preference interactions.
- The request for a building wide ecosystem very much supports application neutral IP based communication systems, with open object models and API's, that allow seamless profit from data-integration across today's application silo's, and that are open for multiple parties to provide adjusted support for specific needs.

A key innovation of the **OpenAIS Architecture** achievement is the low latency group communication **OGC (OpenAIS Group Communication),** that allows to deliver lighting commands to many controlled light points in parallel. In addition to resolving the latency and scalability issues, OGC provides the base for an elaborated **out-of-the-box operation** that supports the electrical contractor best, and induces **operational compatibility across different IoT frameworks and their (future) versions**. Using OGC a low latency local "group agent" for User Interfaces and distant (e.g. cloud based) control is made available, that also provides the needed fast response and **resilient operation** of the lighting when the connection to cloud control is lost or slow.

The full featured Lighting Controls Object Model supports the use of OGC to its best by providing **bandwidth optimized status** information transport together with a systematic support for complex controls requirements, e.g. when controlling a center luminaire of crossing aisles or by e.g. applying node based priority schemes for integrated emergency lighting features.

The **security and privacy** design of OGC is designed to provide sufficient protection independently from firewalls, so the future principles of "**deep defense**" have been anticipated and already integrated.
These principles are applicable to support other building controls services in the future, and we expect they may be picked up once also the BMS services start moving towards an open CoAP / IP based architecture.

For the application layer of the OpenAIS project, a dedicated Object Model was developed, as investigations showed that public models like IPSO were much too limited for advanced high quality lighting control and simple integration into BMS's.

The architecture showed its great potential by serving a **full featured full-scale office** lighting control system (400 luminaires with embedded sensors). It was validated and demonstrated in a **real-life pilot** in an industrial heritage buiding, the "White Lady" building in Eindhoven. Despite the many technical challenges encountered in the realization phase, OpenAIS succeeded in deploying a fully operational multi-vendor lighting control system, based on IoT-standards and frameworks, with IP connection to the end node. This system combined wired and wireless devices from multiple vendors in a single system connected through a standard IT-network with commercial off-the-shelve IT components. The openness of the system was validated by the integration of several additional components, commissioning tooling and user applications, by parties outside the main lighting manufacturers from the consortium, that **seamlessly worked together.**

Final Research on user satisfaction showed **positive reaction of involved users**. However, some **technical attention points** for future product development and system designs remain, especially the **standby energy of the equipment** and the IP interfaces of the nodes **will need some more progress** before the energy data of sophisticated heritage systems can be matched.

1.2 Dissemination of results

1.2.1 Web presence

- Public website: www.openais.eu, Key results and all publications have been published here.
- OpenAIS Promotion Video explaining the objectives and the results of the project, posted on Youtube,
- Video of the OpenAIS light show performed during the Glow light festival in Eindhoven, November 2017. Demonstration of the OpenAIS architecture and pilot implementation possibilities.
- OpenAIS app developed for the pilot users, available in Google Play Store and Apple App Store
- Video "Virtual prototyping for lighting IoT systems", showcasing the OpenAIS pilot virtual prototype.
- Repost of the OpenAIS promotion video on the Thread Group website (planned).

1.2.2 OpenAIS Symposium

A full day symposium was organized in the pilot location of the famous 'Witte Dame', in Eindhoven on May 23rd 2018. 58 Delegates from all over Europe came together to participate, experience and discuss the results of the project (86 people registered in total). Press report in LED Professional magazine.

1.2.3 Contributions to conferences

26 contributions to industry conferences and 10 to scientific conferences were made, see table 1 and 2.

Industry Conference	Title	Partner	Date
SmartLighting Conference '15	OpenAIS: Towards an open system architecture for IP connected lighting, S.M. Verbrugh	PHL	May 2015
SmartLighting Conference '15	Pulling it all Together, J.A. Sayer	JHC	May 2015
LED Professional Symposium '15	Innovation towards an Open Architecture for Intelligent Solid State Lighting Systems	TRI	Sep 2015
SmartLighting Conference '16	OpenAIS: an open system architecture for IP connected lighting	PHL	May 2016
SmartLighting Conference '16	Future embedded lighting controls requirements and solutions for an IoT based architecture	TRI	May 2016
InfoSecurity 2016	Towards an open system architecture for IP connected lighting (booth and presentation on trade fair)	DYN	Jun 2016
Kottayam, India	Presentation: Evolution of Wireless (Sensor & Actuator) Networks: Dream Vs. Reality	TNO	Aug 2016
Kottayam, India	Workshops case study: Open Architectures for Intelligent Solid State Lighting Systems	TNO	Aug 2016
LED Professional Symposium '16	Security for lighting in IoT – group communication	TRI	Sep 2016
LED Professional Symposium '16	An IoT Architecture for future building management embedded lighting controls	ZUM	Sep 2016
LED Professional Symposium '16	OpenAIS- Selected Scenarios and Use Cases	JCI	Sep 2016
LED Professional Symposium '16	Enabling smart building through the internet of light	TRI	Sep 2016
Thread group meeting (Lisbon)	OpenAIS (LWM2M over Thread Demonstrator) was presented	ARM	Nov 2016
Smart Lighting Conference '17	OpenAIS: An Open Architecture for IoT connected Lighting for Professional Buildings	PHL	May 2017
Smart Lighting Conference '17	To BMS or LMS? That is the Question	JCI	May 2017

Smart Lighting Conference '17	Low Latency and Secure Group Communication for Interoperable Lighting Controls based on IoT	ZUM	May 2017
ARM Research Summit '17	Open Architecture for IoT connected Lighting for Professional Buildings	PHL	Sep 2017
LED Professional Symposium '17	IoT System Architecture of BMS, LMS & BIM	JCI	Sep 2017
LED professional Symposium ‘17	IoT standardization needs and multiple connectivity	ZUM	Sep 2017
Led Professional Symposium '17	How the OpenAIS Group Communication allows secure and low latency interoperable IoT basd lighting controls design	ZUM	Sep 2017
Lighting Europe ILS, Brussels	Open Architecture for IoT connected Lighting for Professional Buildings	PHL	Sep 2017
Innovation market of the Embedded Systems Innovation (ESI) symposium	Modelling Distributed Control Systems, Domain modelling to address increasing complexity	TNO	Oct 2017
ZVEI Connected Lighting Day 2017	How OpenAIS embeds Lighting Controls into the IoT world	ZUM	Oct 2017
VDI-Fachtagung: Lighting & IoT	Eine offene Architektur für Lichtsteuerungen in professionellen Gebäuden auf der Basis von IoT.	ZUM	Nov 2017
IEEE Design Automation Conference '18	Embedded IoT for Commercial Building Applications	NXP	Jun 2018
Thread group all members meeting, June 2018	Overview of OpenAIS Project and Results	NXP	Jun 2018

Table 1. Contributions to industry conferences

Scientific Conference	**Title**	**Partner**	**Date**
IEEE SLESC Conference '16	Bandwidth issues in IP based Lighting Controls	TRI	May 2016
ACM DIS 2016 (presentation and proceedings)	Designing Multi-user Lighting Interfaces: Four strategies to implement Social Translucence (T.C.F. van de Werff, K. Niemantsverdriet, H.A. van Essen, J.H. Eggen)	TUE	Jun 2016
SOSE 2016, Norway	Transition from closed system to Internet of Things: A study in standardizing building lighting systems	TNO	Jun 2016
IEEE ICCN 2016	Dependability Analysis of Asynchronous Radio Duty Cycling Protocols (S.S.Guclu, T.Ozcelebi, J.J. Lukkien)	TUE	Aug 2016

IEEE FiCloud'16	Choosing your IoT Programming Framework: Architectural Aspects (L.F. Rahmani, T.Ozcelebi, J.J. Lukkien)	TUE	Aug 2016
IEEE Global Communications Conference '16	Improving Broadcast Performance of Radio Duty-Cycled Internet-of-Things Devices (S.S.Guclu, T.Ozcelebi, J.J. Lukkien)	TUE	Dec 2016
IEEE ICNSC Conference '17	Bandwidth issues in IP based Lighting Controls	ZUM	May 2017
ACM DIS '17 (presentation and proceedings)	Evaluating Interface Characteristics for Shared Lighting Systems in the Office Environment (T.C.F. van de Werff, K. Niemantsverdriet, H.A. van Essen, J.H. Eggen)	TUE	Jun 2017
ACM DIS '17 (presentation and proceedings)	Interacting with the Internet of Lighting (T.C.F. van de Werff)	TUE	Jun 2017
CHI Conference on Human Factors in Computing Systems (presentation and proceedings)	Share and Share Alike? Social Information and Interaction Style in Coordination of Shared Use (K. Niemantsverdriet, T.C.F. van de Werff, H.A. van Essen, J.H. Eggen)	TUE	May 2018

Table 2. Contributions to scientific conferences

1.2.4 Publications in journals and magazines

10 publications in journals and magazines were made:

Journal and magazine	Title	Partner	Date
LED Professional	Newsflash on OpenAIS project – Ideation and Roadmapping Workshop	PHL	Jun 2015
Energies journal volume 10 issue 8, 2017	The Internet of Lights: An Open Reference Architecture and Implementation for Intelligent Solid State Lighting Systems (E. Mathews, S. Guclu, Q. Liu, T. Ozcelebi, J. J. Lukkien)	TUE, TNO	Aug 2017
ILI GLOW Magazine, November 2017	The Internet of Lighting: download and play! (Interview with W. Werner)	ZUM	Nov 2017
ILI GLOW Magazine, November 2017	OpenAIS Pilot in 'De Witte Dame'	TUE	Nov 2017
Journal of Industrial Information Integration	The Impact of the Internet of Lighting on the Office Lighting Value Network (T.C.F. van de Werff, H.A. van Essen, J.H. Eggen)	TUE	Jan 2018
LED Professional	Top Event announcement in LED Professional News report of the OpenAIS Symposium	PHL	Mar 2018

LED Professional	International and cross-industry projects such as Openais are absolutely crucial to the success of connected lighting (interview with Jens Herter)	TRI	May 2018
LED Professional	OpenAIS Symposium on IoT lighting - Final project results	PHL	May 2018
LED Professional Review #67	OpenAIS Integrating Lighting in the Internet of Things,(Frank van Tuijl and Ben Pronk)	PHL	May 2018
LED Professional Review #68	Challenges of the IoT integration in lighting controls components, (Ben Pronk and Stefan Verbrugh)	PHL	Jul 2018

Table 3. Contributions to journals and magazines

1.2.5 Publications planned after the project end

11 publications have been planned for late 2018 after the project end, listed in table 4.

Conference	Title	Partner	Date	Type
Trends in Lighting '18, Bregenz	Interacting with Office Lighting, an end-user perspective (T.C.F. van de Werff, H.A. van Essen, J.H.Eggen, K. Niemantsverdriet, S.A.M. Offermans)	TUE	Sep 2018	Presen-tation
LED Professional Symposium '18	OpenAIS: Advantages of IoT connected lighting in reality (Stefan Verbrugh, Frank van Tuijl and Ben Pronk)	PHL	Sep 2018	Presen-tation
LED Professional Symposium ,18	OpenAIS booth with demonstrations	PHL	Sep 2018	Booth
LED Professional Review #69	User evaluation of the OpenAIS pilot installation (T.C.F. van de Werff, H.A. van Essen, J.H.Eggen)	TUE	Sep 2018	Article
ACM CHI '19	Evaluating User Experience of Dimming Control over Office Lighting (T.C.F. van de Werff, C. v. Lotringen, H.A. van Essen, J.H.Eggen)	TUE	Jun 2019	Presentation & publication
CSD&M 2018	A domain model-centric approach for the development of large-scale office lighting systems", Richard Doornbos , Bas Huijbrechts , Jack Sleuters , Jacques Verriet , Kristina Ševo , Mark Verberkt	TNO, PHL	Dec 2018	Presentation & Publication (submitted)
MODELS 2018	"Virtual Prototyping of Large-Scale IoT Control Systems Using Domain-Specific Languages", Jacques Verriet, Lennart Buit, Richard Doornbos, Bas Huijbrechts, Raymond Kerstens, Kristina Ševo, Jack Sleuters, Mark Verberkt	TNO, PHL	Oct 2018	Presentation & Publication

Journal t.b.d.	Tentative Title: Multicast performance analysis of Thread protocol: OpenAIS lighting use case	TNO, PHL	2018	Article
journal t.b.d.	Validation of the OpenAIS expected impacts (T.C.F. van de Werff, H.A. van Essen, J.H.Eggen)	TUE	Late '18	Publication
journal t.b.d.	Design and implementation of a Protocol Gateway: Embedding legacy ZigBee Networks into the IoT (A. Bale, M. Verschoor, T. Ozcelebi, J. Lukkien)	TUE	Late '18	Publication
journal t.b.d.	Exploitation of virtual prototyping for system diagnosis and commissioning root cause analysis purposes", based upon OpenAIS case study. Intended authors will be Jack Sleuters, Yonghui Li, Marina Velikova, Jacques Verriet.	TNO	2018 or 2019	Publication

Table 4: Planned presentations and publications after the project end

1.3 Exploitation and Standardisation

1.3.1 Standardisation

The major lighting specific challenges, secure, fast and reliable group communication and serverless (no-internet) operation have been solved in the OpenAIS architecture.

OpenAIS also standardized and proved the interoperability between lighting controls components from various vendors as such opening the route to a complete ecosystem of lighting controls and possibly beyond.

The standardisation strategy was defined as a split approach, pushing different aspects into the most appropriate SDO (Standards Development Organisation), see figure 1.

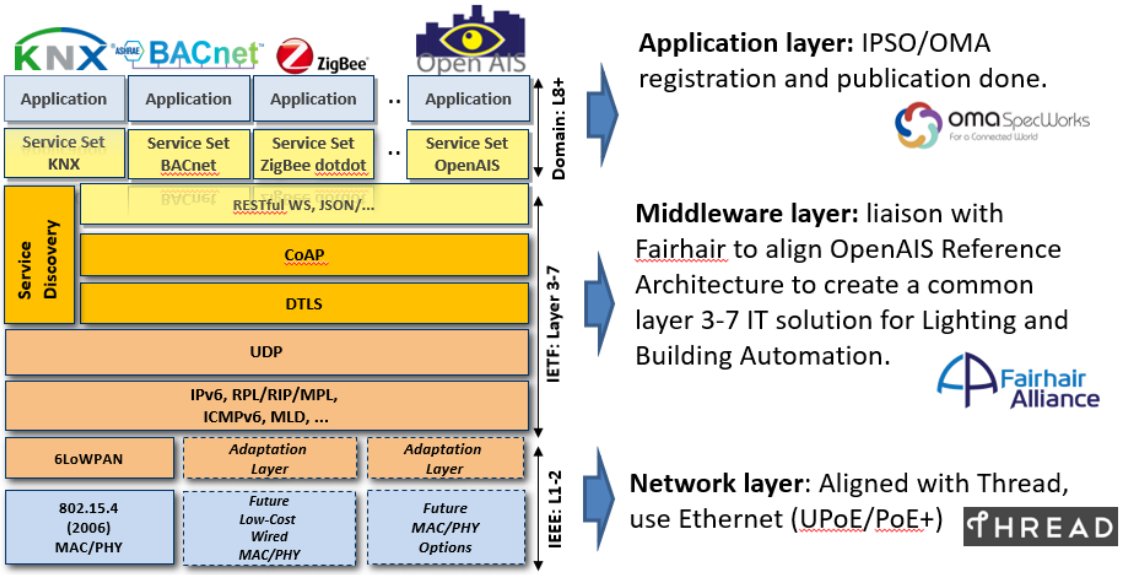

Fig. 1: Overview of standardisation results

1. **The application layer**: The Object Model that was created during the OpenAIS project[2] and that was optimized to serve the 2020's scenario's and use cases, has been accepted by IPSO / OMA as an extension of LWM2M. (published here: http://www.openmobilealliance.org/wp/OMNA/LwM2M/LwM2MRegistry.html objects 3387 - 3406) D2.7 can be considered as an application note for the standard definition.

2. **The "middleware layer":** OpenAIS uses Fairhair to push OGC into standardization. Fairhair is an industrial consortium that pushes a common IoT middleware framework to support the IoT transition of the heritage building controls environments (BACnet, KNX and Zigbee) (Fairhair Alliance). In addition to that the Zigbee Consortium picked the OpenAIS OGC mechanisms and are in the process of incorporating this into their upcoming IP based Zigbee 3.0 and "dot-dot" offer.

   OpenAIS has contributed to Fairhair in the following ways:
   - Input during a series of dedicated OpenAIS-Fairhair workshops
   - Through a set of formal comments on the Fairhair Draft Specifications, as part of the review for scope and direction.
   - OpenAIS input has enabled Fairhair to verify that the application layer object models of OpenAIS matches well with the protocol specification in Fairhair
   - OpenAIS input was used to improve the Fairhair specs
   - Fairhair acknowledges e.g. the OpenAIS pilot as a valuable activity that is complementary to the work of the Fairhair team
   - Fairhair has taken over the approach OpenAIS on multicast security as described in an IETF proposal (link), see point 3) below.

   Fairhair has sent to OpenAIS a letter of thanks, expressing its appreciation for the many contributions from OpenAIS

[2] D2.7, Reference Architecture of the OpenAIS System (link)

3. One of the most critical parts for any IoT system is the **data privacy, the system integrity and the security**. Using group communication is a major threat, as applicable and elaborated security systems are neither available nor standardized. OpenAIS created an IETF initiative and a suggestion to resolve that part, but was not able to get a speedy positive decision on this issue. There is major resistance in IETF to use symmetric encryption for group communications. All discussed alternatives have substantial deficits when applied to lighting and were not accepted by the IETF majority also. The best way forward is to push this through Fairhair also, as this consortium has very similar requests towards privacy and integrity. Fairhair has confirmed to take over and sustain the approach of OpenAIS on multicast security as described in an IETF proposal (link)

4. **The Network layer**: OpenAIS aligns with Thread, as RF Network transport helps with a lot of installations issues when retrofitting lights. However, virtually any IPv6 compatible, CoAP based RF network will be applicable to OpenAIS. We chose Tread as kind of preferred partner, as it offered us the chance to influence their standard to cover some of the lighting needs better than some heritage systems do today. This is mainly about easy and out-of-the-box network joining strategies and about multicast meshing strategies, as requested by the OpenAIS architecture for good reasons. None of those requests is in conflict to (or needs enhancements of) existing IEEE standards, that are today available for the networking layer. Thread is fully using those IEEE standards, but adds some practical aspects that help to commission and maintain an IEEE based RF system in a better way.

   The Thread Commercial Extensions workgroup has expressed interest in the OpenAIS use cases and in promoting the OpenAIS results as showcase for Thread application in professional buildings.

5. **Alignment with DiiA:** The DiiA Alliance is the organization that is responsible for the DALI standard. Currently DALI is by far the most widely used standard for lighting controls in Europe, but it does not exploit the advantages of IP to the end node. The OpenAIS team has presented the OpenAIS results to the DiiA board in a meeting on April 11, 2018 and proposed how DiiA could adopt the OpenAIS architecture as their future standard, either replacing DALI or in addition to DALI. DiiA has not yet identified (at least not communicated) their strategy towards IP connectivity. The OpenAIS team has had several meetings with the DiiA board about possible future adoption of the OpenAIS architecture and Object Model, however without a conclusion yet.

1.3.2 Joint Exploitation

Open Source Initiative: To further enhance the practical acceptance and spread of the OpenAIS results the consortium partners will investigate the possibility of creating and maintaining the startup of an open source community, that further promotes and develops the non-differentiating core of OpenAIS, providing applicable software stacks, at royalty free conditions for commercial use, and maintaining the efforts that ensure interoperability in the future. Two Open Source scenarios are still in consideration at the industrial partners:

1. Make the OGC middleware stacks as they are developed available under OSS licence conditions within the ARM Mbed platform and ecosystem.
2. Several companies jointly establish an organisation that develops and maintains a product grade middleware stack, providing the non-differentiating features of the OpenAIS architecture and that makes it available for the whole industry.

Although there is a positive attitude with the partners towards the proposals, no positive management decision could be reached yet and the decision process is continuing.

1.3.3 Exploitation per partner

Philips Lighting
Philips Lighting has recently re-branded their IoT solutions for IoT connected lighting to Interact Office, which is a proprietary standard. It includes propositions based on wired and wireless networking. The current Philips Interact Office Wired proposition is based on the first lighting system with IP to the end node that was deployed in a large office, i.e. the Philips Installation in the Edge in Amsterdam. The current proposition is a further improved version.

For the development of wired and wireless IoT lighting systems, Philips exploits the results of OpenAIS, in particular:

- Knowledge created in WP1 on scenarios and use cases, as derived from the stakeholder interviews. Since many stakeholders were interviewed and the results were thoroughly analysed, the scenarios and use cases as documented in D1.1 are very valuable as a guide for the development of IoT office systems under the Interact brand.
- Knowledge on architecture as developed in WP2
- Experience from the pilot installation at White Lady, including the results and the knowledge gathered in WP4.

Philips has been a driving force in many lighting consortia and standardization bodies, a position it intends to maintain the coming years. The activities initiated by OpenAIS have been proposed to various SDO's. The proposal for creating or enabling an open source community that further promotes and develops the non-differentiating OpenAIS middleware solution (see section 4.4) is still under management review and has not been concluded.

Philips Lighting aims at a future standard where networking, communication and basic functionalities are open. An important aspect of Philips' exploitation strategy is to use the omnipresent luminaires as a valuable infrastructure. For example, information from the space can be leveraged to bring greater value to the overall building efficiency and personal productivity of office workers. Another example of a proposition beyond illumination is the extension of the Philips Lighting Indoor positioning system for Retail[3] to similar propositions for Offices. Exploitation will happen in Philips Lighting's currently existing channels for Office lighting products:

- Connected luminaires: Philips is the world's largest manufacturer of luminaires with activities in all countries in Europe. In particular in Europe Philips Lighting

[3] Philips Indoor positioning has been recently rebranded to **Interact Indoor Navigation**

as a strong position. Most of the luminaires sold in Europe are manufactured in Europe, e.g. in the Philips factories in Ketrzyn Poland and Tamasi in Hungaria. Philips is currently leading the transition to connected lighting though its PoE system launched in 2014 and currently sold under the commercial name InterzatOffice. Philips is aiming at maintaining its leading position with luminaires communicating though open networking protocols delivering benefits beyond illumination.
In addition to Europe, Philips has luminaire factories and sales activities in all regions of the world, hence reaching economy of scale for development and standardization efforts.

- Controls systems addressing the needs that are described in D1.1.
- Connected drivers: Philips is the worldwide leader in LED drivers and is selling drivers to most of the luminaire manufacturers as part of their OEM offering.
- Services: Philips has started a separate business line on Services, including Managed Services, aiming at exploiting customer value as identified in WP 1.

Tridonic

Tridonic started its investigation into IoT architectures in 2014 and has been developing hard and software for an IP-based lighting controls systems. The device offering of Tridonic contains LED driver, sensors, communication modules and border router. This development was carried out in parallel to the OpenAIS project. Essential buildings block found its exploitation in the architecture of the TRIDONIC offering. In detail Tridonic is offering IoT ready devices as listed here:

- TRIDONIC developed 3 types of LED driver::
  - net4more driver 50 W
  - net4more driver 75 W
  - net4more driver 45 W
- TRIDONIC developed 3 types of communication modules:
  - net4more comModule un:c-Ethernet
  - net4more comModule un:c-PoE
  - net4more comModule un:c-wireless
- TRIDONIC developed a Border Router
  - net4more borderRouter PoE-Thread
- TRIDONCI developed a Sensor:
  - net4more Sensor 5DPI 14f un:c (SE)

The results of OpenAIS are exploited in the above mentioned devices and will be continued to be developed.

Tridonic has started the launch of Net4More (https://www.tridonic.com/com/en/products/net4more-IP-connected-lighting-system.asp) which exploited the results of OpenAIS. Discussions with DiiA, Fairhair and IETF are supported in the sense of standardization of IoT solutions for the lighting industry.

Zumtobel

Zumtobel is embarking on the journey to IoT in parallel of the development done in Tridonic. The first IP based luminaires where produced for the OpenAIS project and found its usage in the pilot setup of OpenAIS. Two luminaire families from Thorn and Zumtobel lighting where designed with integrated IP components. Zumtobel will exploit further the usage of IP based luminaires and will build upon the founding of OpenAIS.

This is in line with the started Zumtobel Cloud based services with which Zumtobel sees a development into optimized maintenance of lighting installation. It is welcome by Zumtobel that IoT solutions and products will be available in future. The experience especially in the production of IP luminaires will guide the future process of IP luminaire production. Zumtobel supports and will drive further exploitation steps into the lighting industry. Especially with the path in the direction of DiiA, Fairhair and IETF Zumtobel actively companions the further exploitation of OpenAIS results.

With the project of OpenAIS, Zumtobel designed IoT ready luminairs

Dynniq

The 3 key elements of the exploitation plan are:

1) Include wired and wireless lighting communication networks in the services capabilities. Dynniq created such scope extensions in the past, for example installation services from pure IP network installations to include also application services like Voice over IP, IP Camera and IP based traffic solutions.
2) Exploitation of the Dynniq Belgium instance of the configuration tool to support the installation, commissioning and remote monitoring of any OpenAIS project in Europe.
3) Transfer the OpenAIS knowledge, especially around IoT, beyond installations in office buildings; potentially into the own Dynniq products in mobility, parking and energy e.g. towards public (outdoor) lighting systems.

NXP

NXP has continued alignment and preparation of NXP solutions and SDKs to provide features based on OpenAIS architecture and development to NXP's wide range of customers - industry leaders as well as mass market.

To this point, the following actions have been started and are on-going or are planned after M42:

1. Definition of a set of **Reference Designs** (development hardware and firmware solutions) based on NXP current and next generation microcontrollers (MCUs) and application microprocessors (MPUs) with integrated connectivity and security components which will offer NXP customers a head-start in development. The reference designs will consist in a generic, basic OpenAIS system which NXP customers can then further enhance with specific differentiation as they develop products or services.
2. Selective integration of OpenAIS concepts, architecture and feature sets into base MCUXpresso SDK for the Kinetis-K, Kinetis-W and i.MX product ranges.
3. Incorporation of OpenAIS system concepts into definition of next-generation (release estimated 2019-2021) MCUs and MPUs (e.g.: integrated connectivity and hardened secure enclaves, memory and device size vs. cost balance).
4. Supporting any commonly agreed collaborative maintenance of OpenAIS result with all or a subset of current partners.
5. Alignment and support for OpenAIS project results appropriate for future standardization into standards development organizations in which NXP participates included, but not limited to: Thread Group, Fairhair Alliance, Bluetooth Special Interest Group and the Zigbee Alliance.

Johnson Controls

It is part of Johnson Controls' desire to capture more lighting controls projects, especially in Europe, by learning from OpenAIS and using our involvement to establish credibility in the space.
Johnson Controls' well known modus operandi is to use IP convergence and BACnet in the building services network arena to bring together more systems and to be "Smart". Since merging with Tyco in late 2016 more major building systems (e.g Fire and Security) were added to our direct capability but there is no in house lighting product.
Progressive sales branches are now engaging in the Master Systems Integrator concept where they recognise the growth opportunity of adding lighting controls and integrations into their portfolio of services. Of course they have to overcome their local barriers between mechanical and electrical route to market and the specifications still being standalone DALI systems or no controls at all.

Through OpenAIS we have learned a great deal about Use Cases and Scenarios and had to pitch a modern value proposition to several potential pilot candidates including a tough extended sales cycle with the final pilot site. All this helped us understand more deeply the state of the art Digital Building (lighting) proposition from Cisco that we publicly support.
Part of the WP1 and WP5 leaders' role inside Johnson Controls has been to disseminate this knowledge and to educate the EU branches in their foray into DALI controls and digital POE lighting, and to steer them through considering a local strategy by building a delivery ecosystem with lighting and controls suppliers. Working through the supply chain with sales, suppliers and clients the presentations have been framed around involvement with OpenAIS to establish our credentials and credibility with the audience.

Work on the BMS connection has exposed gaps (opportunities!) in the way even today's BMS and lighting controls are integrated and can be improved. The work will be founded on scenarios and use case resolution. This work though is hosted in the USA. There is an active outdoor and indoor lighting operation and the people concerned have been briefed on OpenAIS and have consulted the EU team on future developments for the integration of lighting controls, ubiquitous data collection and analysis. The integration between Digital Building and Metasys is expected to improve as a result.

The HVAC industry is ahead of lighting in the BIM arena especially on the design and estimation side and it is normal for the plumbing and pipes and valves to be specified as 3D RevIT files by product managers . Working partly through a typical retrofit where we have scanned the site, added lights and exported to an open database that can be read by a prototype tool has taught us a lot about the usefulness of this technology and opened the eyes of the lighting partners to its power too. BIM for lighting and networks is not standardised enough and is progressing slowly but already lighting designers are trying to use it and it needs our attention.

ARM:
For Arm the original exploitation plan proceeded in stages. The first stage was to develop a Wi-Fi -like low power radio access point capable of being managed as part of IT networks. The second stage was to demonstrate in the pilot the demand for and utility of such access points. The third stage required third party access point vendors to assess this feature as an opportunity for themselves such that they would put it into commercial production, so that the lighting industry could buy such access points off the shelf as ordinary IT networking equipment. By establishing Thread as a widely available and

reliable technology this was to create demand for Arm's connected product software platform Mbed, which includes a Thread implementation. Although the third stage has not happened yet, OpenAIS results have come very close by a) enabling the Fairhair Alliance to include Thread as part of its technology stack, and b) providing a Low Power Radio Access Point reference design that has been proven in three separate realisations by OpenAIS project partners and now becomes a valuable resource for any user of Mbed OS Thread.

Additional exploitation opportunities have been seized in the course of the project. The demonstration of a converged IP-based network as not only achievable but also cost effective for lighting and buildings controls, even including low-power wireless, is a valuable case study for Arm marketing. The key OpenAIS results of a converged IP network, proof of utility of Cisco UPoE "Digital Ceiling" routers, the development of robust and cost-effective "loop and star" network topology, the public example of Mbed OS being used successfully in a product-quality standards-based connected lighting system, development via the IETF of secure CoAP multicast capability "Open Group Control", and the easily-realisable Thread Low Power Radio Access Point reference design are all important components of this case study. Arm exploits these results in marketing aimed at developing demand for Mbed by encouraging OEMs in the lighting and buildings controls sector to begin connected device projects, and to design in Mbed. Insights into lighting use cases and requirements have been used to specify requirements for new Mbed features in development, further increasing design wins.

Mbed itself is a strategy to realise growth for Arm through two channels. First, as a capable embedded software environment for use with Arm microcontrollers in connected devices, it helps Arm-based microcontrollers win "sockets" in more projects, including lighting projects. These design wins are reflected in revenue growth in Arm's traditional chip royalty-based business model. Second, as a provider of proprietary cloud services ("Mbed Cloud") for the management of fleets of connected devices, design wins for Mbed embedded software represent a opportunities to sell Mbed Cloud services subscriptions. These are reflected in a new line of business for Arm, launched during the course of the OpenAIS project.

TNO:
The TNO OpenAIS activities are part of TNO's major Model-Driven Engineering (MDE) / virtual prototyping approach. All results (WoW and tools) from the OpenAIS project will become part of that approach and are available for all interested parties in TNO's high-tech systems industry eco-system. Already in 2017 the Philips Lighting PLS (Professional Lighting System) division started to adopt key parts of the DSL / virtual prototyping approach for specification, design and verification of the next generation of connected lighting systems for the professional office market. Furthermore, Thales Netherlands have shown interest and is starting a pilot on the DSL / virtual prototype approach tailoring their naval systems.

Two Master Students graduated in 2017 under supervision of TNO on to OpenAIS related research topics:

- "Developing an easy-to-use Query language for verification of lighting systems", L. J. Buit. 2017. University of Twente (http://essay.utwente.nl/74020/)

- “Feature composition for lighting systems””, R. J. C. M. Kerstens. April 13, 2018. Eindhoven University of Technology - thesis access restricted (under

TUE:

Exploitation of OpenAIS results by TUE include e.g. the following education activities:

- An Internet of Things (IoT) course containing a lot of insights gained from the OpenAIS research. From the start of the course in 2015/2016, about 300 students attended this course and it is expected that this number will grow in the coming years.
- OpenAIS results have been incorporated in the interdisciplinary master course "Physics of Light and Lighting Design”.
- At the Department of Industrial Design, the cases and content of the OpenAIS project are the basis for realistic design projects with an enrolment of 2 times 20 Bachelor and Master Students each year
- 15 Master Students graduated in 2015-2018, 2 planned for late 2018:
    - Pingping Lin: master thesis; “Determining the Relative Position of a Device”
    - Liu Di: “Control Object placement”
    - Tibor Beke: master thesis: “Time synchronization in IoT lighting control”
    - Li Gong: master thesis: “Automatic Commissioning Of Wireless Lighting Systems”
    - Wouter van der Wal, The transition to cross ecosystem user experiences, (Master thesis Department of Industrial Design, Advisor: H. van Essen)
    - Ankith Bale, IoT Gateway for Connecting Legacy Networks to Fairhair IoT
    - Tibor Beke, Time synchronization in IoT lighting control
    - Aleksandra Wrońska, Contextual use of connected lighting at home
    - Joren Broekema, Bloom: Light Interface for Shared Environments
    - Zheng Chen, Software Update for Internet of Things using the Lightweight Machine to Machine Protocol
    - Charlotte van Lotringen, Individual Lighting Control: An Effective Way to Increase Employees' Perceived Control and Satisfaction?
    - Yongmin Qiu, Beacon synchronization for indoor positioning (co supervisor NXP)
    - Linglin Zhang,Message obfuscator for OpenAIS lighting system (co supervisor PHI)
    - Srikanth Sistu, Thread Networking Testbed for Performance Analysis of Wireless Mesh Networks,(TU/e and Philips Lighting Co-supervised project. Promoter: Tanir Ozcelebi. Company Supervisor: Esko Dijk. University Supervisor: Qingzhi Liu), Planned Sept 2018
    - Ziyuan Zhao, QoS-Aware Distribution and Deployment of Lighting Control Behaviors, (TU/e and Philips Lighting Co-supervised project. Promoter: Tanir Ozcelebi, Company Supervisor: Ben Pronk. University Supervisor: Qingzhi Liu), Planned Sept 2018

- 1 TU/e PhD dissertations:
    - T.C.F. van de Werff (planned early 2019)

2 Conclusions on the project

The project created everything that is needed to enable professional lighting controls on top of IPv6-based communication. Latency, security, interoperability, resilience, multivendor and scalability issues have been fully addressed and resolved. The results have been verified by both simulation and full scale demonstration.

The Technology is ready for use now.

However, some of the commercial and supply chain parameters suggest that a successful IPv6 based offer for a wider professional lighting market will be possible in 2-4 years only. This is both due to still immature and evolving IoT stacks and the related resources needed for a full secure IPv6 implementation in a lightweight node, and as well for necessary advances in the IT backbone: Especially the overall energy consumption and the service cost for managed IT ports are prohibitive today and need some substantial progress.
The same applies for the related security standards for group control: Discussion on details of that standard are still ongoing in IETF, as multiple additional requirements from other applications need to be considered, it may take substantial time before a standard can be agreed on.

The project explored the use of multiple IPv6 based connection technologies: ETH/LAN, PoE, and the most recent and promising wireless system ("Thread commercial extensions", that is itself based on 6LoWPAN). It demonstrates that a seamless control independent from the connection technology is both possible, is on the edge of availability, and that its performance is sufficient.
While RF connections are most promising in terms of overall energy consumption and wire handling especially for refurbishments, their connection stability and bandwidth considerations need much higher planning and maintenance efforts to ensure decent operation, and this is suspected to somehow compensate the energy benefit over lifetime.

The integration effort the project performed, also uncovered the lacking maturity of some of the PoE and RF offer: the related software stacks are not yet of commercial grade, the applied standards are still evolving, and the estimate is that it will take most likely 1-2 years before it can be assumed "fully implementable", without the risk of unstable deployments and missing future standards definitions.

The pilot validation further identified several gaps and challenges in the present situation:

- Wired IPv6 communication is substantially expensive per port. Therefore wireless communication is expected to be the way forward, especially for retrofit installations
- Wireless IPv6 network components are not mature enough today The wireless stacks are still maturing, e.g. the Commercial Extensions specification of Thread Group will be not ready before the end of 2018.
- The standby energy consumption is still high, especially for wired connections. OpenAIS used UPoE compliant IT equipment for the pilot, consuming significant power per port. Soon a new PoE standard will become available (IEEE802.3bt) and this standard was created with lighting as the leading application with stricter stand-by power requirements. We expect future IT equipment to better fit into the lighting requirements.

- BIM is not ready to provide the needed semi-automated commissioning It is the role of BIM, to provide the data needed for a semi-automated commissioning over the wire. However, BIM is not ready yet, controls-relevant information and design templates for LED lighting are still missing.
- BMS not ready for grouping, location and discovering ubiquitous IoT object data. Of course, integration is possible today and has been shown, but some major benefits of IoT based lighting controls will materialize only after BMS joins this way into an IoT based, open protocol future.
- The cost of microprocessors is still high with sufficient resources to fulfill low latency encrypted IPv6 based communication. These are expected to reduce over time, partly driven by Moore's law and partly driven by increasing volume.

A successful commercial offer for a wider market will need 2-3 years of further evolvement of the IoT environment it is embedded in.

3 Socio-economic impact of the project

Impact expected by the call	Contribution by the project	Progress so far
Reinforced industrial leadership in intelligent lighting systems and related devices fabricated in Europe	Increased international competitiveness of the European lighting value chain to provide next generation intelligent lighting systems. Keep current strong position and extend it by developing Internet based lighting systems. Make the architecture available to the whole industry through standardisation.	The Reference Architecture was made publicly available, the object model API definitions have been listed and published through the OMA/IPSO. OGC has been transferred to Fairhair Alliance for adoption in the Lighting and Building Automation industries. OpenAIS has directly driven contributions in SDOs including Thread Group, OMA/IPSO, DiiA, and IETF.
	Opportunities for European companies to develop new business models for new added value services e.g. intelligent demand response applications linking Smart grid with lighting systems	Opportunities are technically enabled by the open Reference Architecture with its open Object Model and APIs and the control stacking scheme.
	An industry accepted architecture for a new application domain, employing all new features in existing buildings, which will be the majority of the lighting market in the 2020's As a result of OpenAIS the European lighting industry will learn how to service existing buildings.	Architecture specifications have been published. Creating market acceptance is part of the dissemination and standardisation efforts. Preferences for Fairhair, Thread and Zigbee dotdot are emerging in the lighting industry but the take-up is expected to take 3-4 more years.
	Currently European lighting companies are highly competitive and most of the systems are developed in Europe. As a result of OpenAIS, they will strengthen their competitiveness.	The consortium and advisory board builds on the industry leaders of the EU lighting industry. Joint endorsement will strengthen their competitive position towards the rest of the world. OpenAIS architecture provides a common non-differentiated framework that supports commercially differentiated solutions. Hence it strengthens competiveness and openness and reduces market fragmentation
	An early involvement of the lighting value chain in IT	IT industry is a clear stakeholder in the consortium

Impact expected by the call	Contribution by the project	Progress so far
	architectures will act as a catalyst for the IoT adoption and will create a market for related applications, leading to additional employment in the European lighting and IT industry.	and the advisory board. Their requirements, concerns and solutions are taken into account as reflected in the WP2 results. Outreached to the ARM MBED developers ecosystem, Thread Group, OMA/IPSO, and IETF where IT industry is well represented.
	Faster adoption by building owners, because of multiple vendors delivering modules, software stacks, devices, etc. all being part of the open architecture	The open OpenAIS Architecture and standard interfaces are expected to speed up the adoption by building owners.
Market introduction of intelligent lighting systems based on open system architectures and standardised interfaces	Improved economy of scale due to the existence of a leading standard (lower cost of ownership): Wide-range of non-lighting applications can be linked to the lighting platform, which will reduce number of operational platforms in a building.	Adoption of standard IoT-based Architecture as specified by OpenAIS enables de-siloing of Lighting and Building automation functions. This enables the reduction of the platform count in a building
	More efficient use of office space, as office space is expensive: a lighting system that can be configured around changing usage of the space, is advantageous	Has been part of the requirements researched by WP1, and is fully enabled by the architecture and Object Model platform
Major benefits for the users through the wide market introduction of intelligent lighting systems based on open system architectures and standardised interfaces	Improved economy of scale (lower cost of ownership): Wide-range of non-lighting applications can be linked to the lighting platform, which will reduce the number of operation platforms in buildings	Has been part of the requirements researched by WP1 (Building Wide Ecosystem) and has been designed in in the OpenAIS architecture specification
	More efficient use of office space, as office space is expensive, a lighting system that is configurable with the changing usage of the space, is advantageous. An app allowing more efficient office space usage will be developed in the project. After the project, numerous apps will be developed by many companies.	The requirements for the 2020's have been identified around 3 main scenarios: Easy Life, Increase Building Value and Building Wide Ecosystem. The OpenAIS Architecture specification provides an infra-structure to create such services.
	More than €300 billion will be saved annually on the global energy bill	Market surveys predict that IoT based intelligent energy management systems can reduce energy use in Offices by 20% in 2025. However, we expect that the main lever is the increase of acceptability

Impact expected by the call	Contribution by the project	Progress so far
		of networked lighting controls (rather than a more sophisticated functionality), and we estimate that open, IoT based lighting controls will increase the market size by factor 10 (current controls market size is some 180 M€ in Europe only)
	The new lighting system will allow numerous applications that make the building more comfortable and efficient to work in. An example application will be developed in the project showing major benefits for office workers	The pilot has demonstrated example use cases that provide clear benefits to all stakeholders, including office workers.

4 Link to the project website

http://www.openais.eu/

5 Project logos, diagrams, photographs and videos illustrating its work

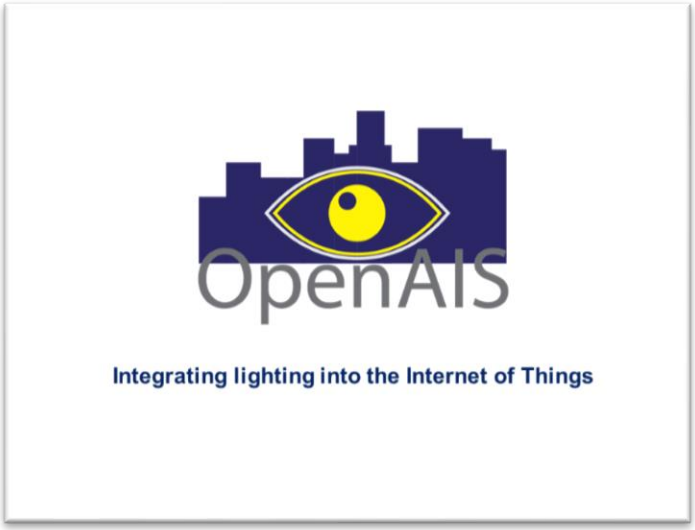

Fig. 2: OpenAIS Logo

OpenAIS Promotion video: https://youtu.be/kaWEh1jAqLA

Fig 3: Pilot location on the top floor of the White Lady industrial heritage building in Eindhoven

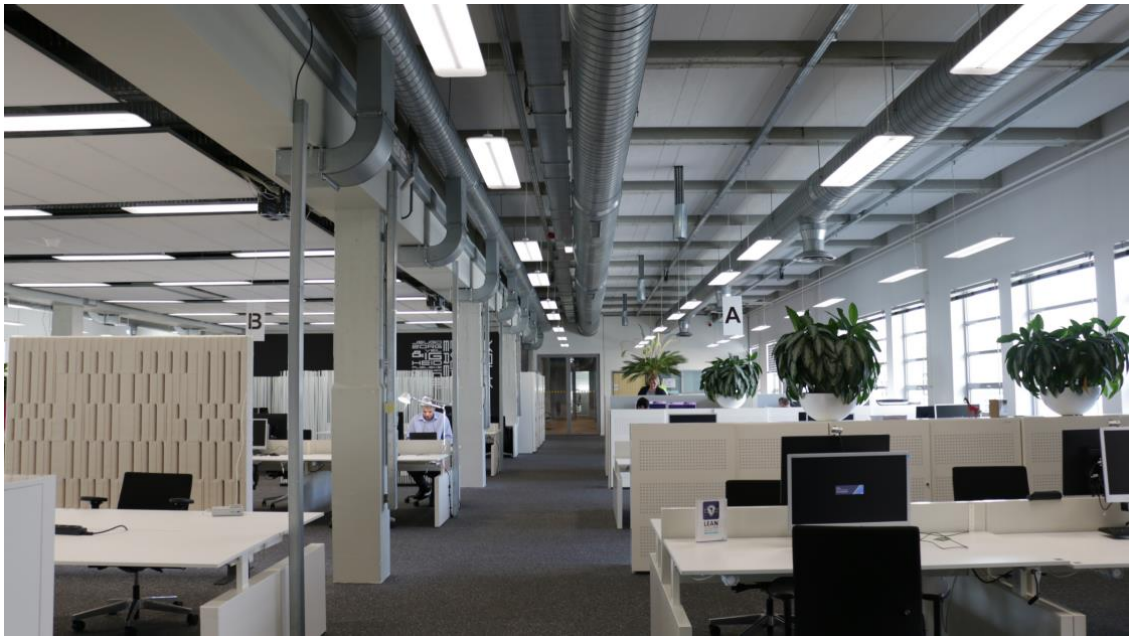

Fig. 4: Impression of the Pilot Office

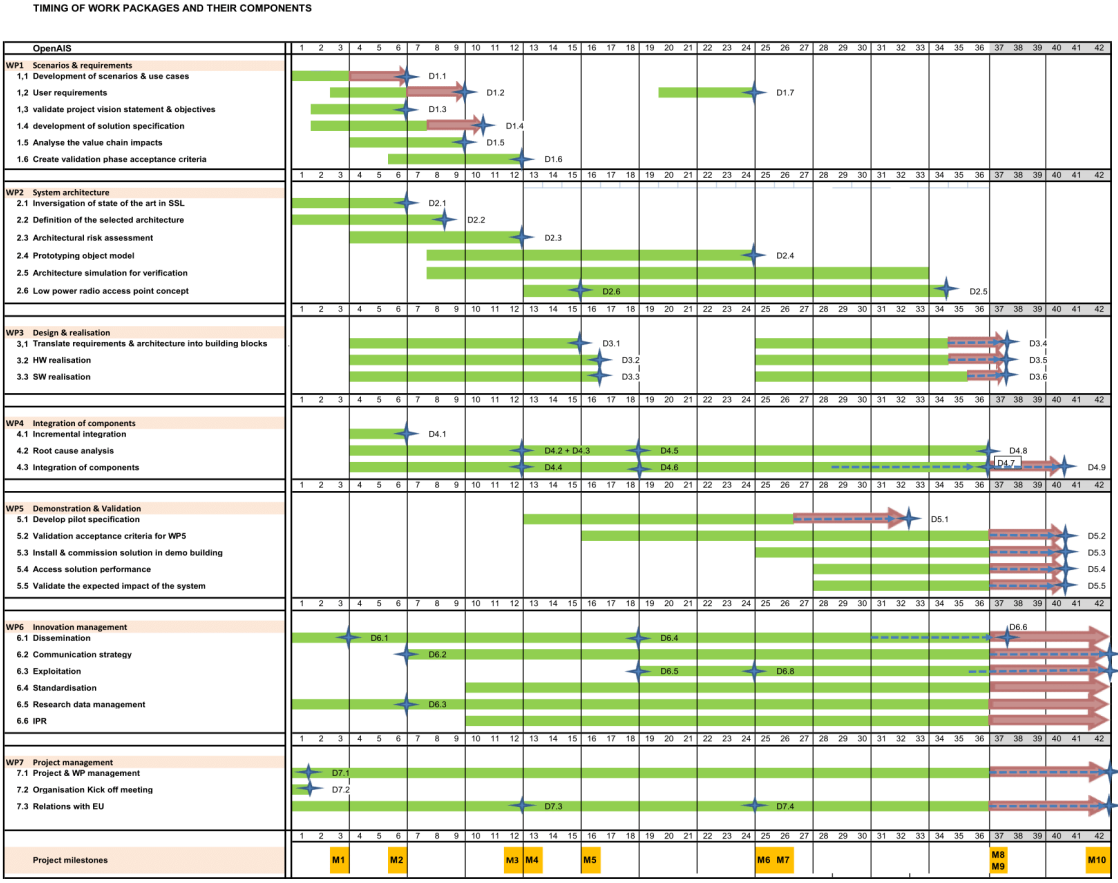

Fig. 5: Timing of workpackages and components