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- COST -

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COST 4129/11

MEMORANDUM OF UNDERSTANDING

Subject : Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action IC1101**:** Optical Wireless Communications **-** An Emerging Technology

Delegations will find attached the Memorandum of Understanding for COST Action IC1101 as approved by the COST Committee of Senior Officials (CSO) at its 182nd meeting on 17 May 2011.

MEMORANDUM OF UNDERSTANDING

For the implementation of a European Concerted Research Action designated as

COST Action IC1101

OPTICAL WIRELESS COMMUNICATIONS - AN EMERGING TECHNOLOGY

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4154/11 Rules and Procedures for Implementing COST Actions, or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to increase the scientific understanding and technical knowledge of the emerging field of optical wireless communications.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 48 million in 2011 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter IV of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

Wireless transmission via optical carriers opens doors of opportunity in areas as yet largely unexplored. Offering significant technical and operational advantages, optical wireless communication (OWC) can be, in some applications, a powerful alternative to and, in others, complementary to existing radio frequency (RF) wireless systems. Variations of OWC can be employed in a diverse range of communication applications ranging from very short-range (on the order of millimetres) optical interconnects within integrated circuits to satellite links (larger than 10,000 kilometres). In many respects, OWC research is still in its infancy and calls for extensive research to begin to harness the enormous potential of the optical spectrum. This COST Action will serve as a high-profile consolidated European scientific platform for interdisciplinary OWC research activities, spanning from characterization of diverse propagation media to modelling, design and development of devices, components, algorithms/protocols and systems. It will make significant contributions to the fundamental scientific understanding, technical knowledge, engineering design and applications while promoting community awareness of this emerging field. Development of novel and efficient communication technologies resulting from integrated research activities made possible through this Action will be a significant enabler for future-generation heterogeneous communication networks supporting a wide range of wireless services/applications.

Keywords: Optical Wireless Communication, Wireless Communication Technologies, Propagation Modelling and Channel Characterization, Physical Layer Algorithms and Networking Protocols, Photonic Components.

B. BACKGROUND

B.1 General background

The proliferation of wireless communications stands out as one of the most significant phenomena in the history of technology. Wireless devices and technologies have become pervasive much more rapidly than anyone could have imagined twenty years ago and they will continue to be a key element of modern society for the foreseeable future. Today, the term “wireless” is used almost synonymously with RF technologies as a result of the wide-scale deployment and utilization of wireless RF devices and systems. The RF band of the electromagnetic spectrum, spanning from around 30 kilohertz (kHz) to 300 gigahertz (GHz), is fundamentally limited in capacity and costly (i.e., as most sub-bands are exclusively licensed). With the ever-growing popularity of data-heavy wireless communications, the demand for RF spectrum is outstripping supply and the time has come to seriously consider other viable options for wireless communication using the upper parts of the electromagnetic spectrum for applications where access to huge bandwidth is a requirement. Utilization of the optical band of the electromagnetic spectrum for wireless transmission opens doors of opportunity in areas as yet largely unexplored. Optical frequencies range from 300 GHz to 300 petahertz (PHz) and include infrared, visible and ultraviolet bands – a spectral range that dwarfs the 300 GHz that the RF band represents. OWC systems (both indoor and outdoor) offer significant technical and operational advantages such as higher bandwidth capacity, robustness to electromagnetic interference (EMI), a high degree of spatial confinement (bringing virtually unlimited reuse and inherent security), low power requirements and unregulated spectrum. Variations of OWC can be employed in a diverse range of communication applications ranging from very short-range (on the order of millimetres) optical interconnects within integrated circuits through outdoor inter-building links (on the order of kilometres) to satellite communications (larger than 10,000 kilometres).

With its significant advantages and wide range of potential application areas, OWC is one of the most promising current opportunities for high-impact research in the information and communication technology (ICT) area. With its bottom-up approach to support new actions in areas at the frontier of scientific knowledge or of great societal significance, the COST framework provides the best mechanism for supporting OWC-related research activities at a global scale. In line with the COST's mission to support non-competitive and pre-competitive research activities, this COST Action "OPTICal WIreleSs communications - an Emerging technology" (OPTICWISE) aims to serve as an extensive European platform for coordination of OWC research activities that has enjoyed growing attention in the last few years. Through the integrated research capability made possible by OPTICWISE, innovative approaches will be investigated and developed spanning from optical channel modelling to algorithm/protocol development and hardware system research. These concerted research efforts will address the unique challenges in the field of OWC and demonstrate the promise of OWC systems for achieving low-cost, ultra-high-bandwidth, and reliable future-generation heterogeneous communication networks.

B.2 Current state of knowledge

The European research community has a strong interest in both wireless and optical fibre communications as indicated by the large number of relevant projects under FP6 and FP7 programmes. However, research efforts in OWC systems (that can be considered at the intersection of those two dominant research areas) are rather fragmented and less focused in Europe and the rest of the world. The extreme diversity of applications (outdoors, indoors, space, mobile, devices, commercial, military, consumer etc.) has created many niche opportunities which research teams are individually addressing in an ad hoc manner. EU FP6 and FP7 projects most of which only partially address OWC include ATENAA, MINERVAA, CAPANINA, OMEGA, SECOQC, SatNEx, BONE, and E-Photon/One. FP6 projects ATENAA (Advanced Technologies for Networking of Avionic Applications) and MINERVAA (Mid-term Networking Technologies and In-flight Validation for Avionic Applications) have investigated the use of OWC for aeronautical communication applications. Another FP6 project CAPANINA (Communications from Aerial Platform Networks delivering 'Broadband for All') has demonstrated the deployment of OWC links in HAP (high altitude platform) networks to provide wide area, high-capacity wireless coverage in rural areas. The FP7 project OMEGA (Home Gigabit Access) project has explored OWC links for short range transmission in indoor environments.

The FP6 project SECOQC (Secure Communication based on Quantum Cryptography) project has involved the experimental test-bed of quantum key distribution over an OWC link. SatNEx (European Satellite Communications Network of Excellence) is a Network of Excellence on satellite communications funded under FP7. Sub-workpackages in SatNEx2 consider OWC technology for both terrestrial and space applications. BONE (Building the Future Optical Network in Europe) and E-Photon/One are Networks of Excellence and some workpackages therein address the hardware aspects of OWC systems and investigate the potential deployment of OWC as a last-mile solution for metropolitan area network extensions.

Some working groups in the COST Actions IC270 (completed), IC297 (completed), and IC0802 (ongoing) have also addressed OWC in their research agenda. The main focus of IC270 Action (Reliability of Optical Components and Devices in Communications Systems and Networks) was fibre-optic communications while, within its Working Group 1, reliability of terrestrial OWC links was studied. On the other hand, the scope of IC297 Action was limited to HAP networks, which are only a particular application area of OWC and those results cannot be directly applied to other applications. Ongoing IC0802 Action addresses the development of propagation tools for the integrated telecommunication, navigation and earth observation systems. Its Working Group 3 (most of whose members are also involved in this Action) focuses on the channel modelling for terrestrial and airborne OWC systems.

In North America, WOC research projects attract financial support from the National Science Foundation (NSF) in the USA and the Natural Sciences and Engineering Research Council of Canada (NSERC). OWC research is also significantly supported by two US defence research organizations – the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) - see, e.g., ORCLE, ORCA and InPho (Information in a Photon) projects which aim to use OWC links for homeland/national security applications and disaster recovery. Another exciting OWC initiative in the USA is the ongoing effort to launch an NSF Center on Optical Wireless Applications in Imaging, Communications, Networking, and Navigation Systems lead by the Pennsylvania State University.

In the past, OWC has been considered a “niche” technology. The aforementioned projects carried out in Europe and North America have been able to successfully demonstrate the potential and feasibility of OWC for a number of applications in indoor and outdoor environments. However, to establish and consolidate OWC as a mainstream technology, extensive research efforts are required in the following four main areas:

1. Propagation modelling and channel characterization of OWC spectral bands ranging from infrared to ultraviolet frequencies;

2. Establishment of a unified information-theoretic formalism to quantify the OWC channel capacity and development of novel physical layer methodologies (including but not limited to advanced coding, modulation and diversity techniques) to approach these ultimate limits under practical constraints;

3. Development of upper layer protocols and cross-layer designs taking into account the inherent characteristics of OWC links; and

4. Design, fabrication, and characterization of specialized opto-electronic and (micro)-optical circuits/devices optimized for practical realization of efficient and low-cost OWC systems.

The innovative approach required to enable radical advances in OWC will only be possible through the integration of diverse expertise and capabilities to address these four distinct and complementary areas of research in a coordinated fashion. In many respects, OWC technology is still in its infancy and calls for extensive research efforts to harness the enormous potential of the optical spectrum for communication applications. Towards this overall objective, this COST Action will be key to the launch of a consolidated high-profile scientific European platform for OWC interdisciplinary research activities, ranging from devices modelling and design, characterization of the propagation media to the algorithm/protocol design and hardware development.

B.3 Reasons for the Action

The design of pervasive and trustworthy next-generation communication networks is recognized as a major technical challenge that European researchers face in the next ten years. Development of novel and efficient wireless technologies for a range of transmission links is essential for building future heterogeneous communication networks to support a wide range of service types with various traffic patterns and to meet the ever-increasing demands for higher data rates. As the need for the bandwidth rises exponentially, there is an urgent need for transformative and far-reaching solutions. OWC has such promise! It is in fact not a new technology, but it has in the past been overshadowed by wireless RF and optical fibre communications. With recent advances in visible light and ultraviolet communications, the potential of OWC is promising more than ever. There are however so many unknowns in the largely unexplored territory of the optical spectrum. OPTICWISE will be the very first COST Action dedicated solely to OWC and will make significant contributions to the understanding, technical knowledge and broader awareness of this emerging field.

Development of novel and efficient communication technologies resulting from integrated research activities made possible with OPTICWISE will be a main enabler for future-generation heterogeneous communication networks supporting a wide range of services/applications. OWC technology is uniquely positioned to address various connectivity needs in future communication networks, whether in the core, edge, or access. Envisaged OWC applications include, but are not limited to:

- Terrestrial atmospheric line-of-sight (LOS) infrared communication for (a) metropolitan area network (MAN) extension, (b) local area network (LAN)-to-LAN connection to enable enterprise/campus connectivity, (c) broadband access to remote or underserved areas, (d) temporary links for disaster recovery and emergency response, (e) optical fibre back-up, (f) cellular backhaul, (g) wireless video surveillance and monitoring, (h) high definition television (HDTV) transmission, (i) quantum key distribution, and (j) the last-mile access network;

- Indoor infrared in the form of diffuse and LOS links and visible light communications (VLC) for (a) wireless LANs (WLANs), (b) "hot-spot" links at airport, railway station and other public places, (c) aircrafts and high-speed trains, and (d) hospitals, museums and art galleries;
- Infrared communications for ultra-high-speed wireless personal and body area networks (WPANs and WBANs);
- Outdoor LOS and non-LOS (NLOS) infrared and ultraviolet communication for sensor networks;
- VLC for inter-vehicular and vehicle-to-infrastructure networks;
- Satellite communications (e.g., inter-satellite, earth-to-satellite) and deep-space links;
- Space-to-aircraft and inter-aircraft communications;
- High altitude platforms (HAPs);
- Underwater optical communications;
- Intra-chip communications for super computers;
- Chip-to-chip communications in stacked and closely-packed multi-chip packages.

The research results will also benefit other fields in which optical wireless technology can be used. These include the healthcare (e.g., tissue analysis), agriculture, civil protection and security (e.g., local and remote sensing) among others. OPTICWISE will establish a unique consolidated research capability. The expected high-quality research outcomes will contribute significantly to European scientific excellence impacting the worldwide academic OWC research community, relevant ICT industries, and standardisation bodies.

B.4 Complementarity with other research programmes

Please see the relevant explanations in Section B.2.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The aim of COST Action OPTICWISE is to increase the scientific understanding and technical knowledge of the emerging field of OWC by exploring and developing novel methods, models, techniques, strategies and tools in infrared, visible and ultraviolet spectral bands that will facilitate the implementation of future generations of OWC systems. The resulting high-performance, high-reliability, ultra-fast, power-efficient, and low-cost OWC systems are envisioned as an indispensable part of a future wireless eco-system. OPTICWISE will help establish OWC as a mature communication technology and present a powerful alternative and/or complement to existing technologies in a diverse range of communication applications.

C.2 Objectives

Besides enabling scientific advances in the emerging field of OWC, OPTICWISE will also serve as an internationally recognized reference point through capacity building of OWC stakeholders. It will increase awareness of OWC in the scientific community and the general public. It will influence decision makers at national and international levels through the participation in standards bodies and international forums. It will also provide training opportunities for graduate students and early-stage researchers (ESRs) in the OWC field.

C.3 How networking within the Action will yield the objectives?

With attractive features such as high bandwidth capacity, robustness to electromagnetic interference, high degree of spatial confinement, inherent security and unregulated spectrum, OWC stands out as a powerful alternative and/or complementary technology to the existing RF based wireless systems for a wide range of applications. It has the potential of bringing paradigm-shifting advances which can revolutionize the wireless communication industry. However OWC research is in its still infancy, largely fragmented and less focused. The COST framework, by its nature, supports non-competitive research and visionary activities and is complementary to EU FP7 programme. With its bottom-up approach, the COST framework will be invaluable to create a consolidated high-profile scientific platform for supporting development and exchange of knowledge, interaction and collaboration in the growing field of OWC technology.

OPTICWISE brings together more than 50 researchers from European academic and research institutions, government bodies and companies who are involved in research of different aspects of OWC supported by the national and EU FP7 research grants. The Action will synergize the interdisciplinary scientific expertise of European researchers in diverse fields such as the electromagnetic propagation theory, atmospheric physics, meteorology, information/communication theory, networking, communication systems, photonic components, devices and systems. Coordination efforts through this Action will avoid major duplications of research efforts, increase the mobility of OWC researchers in Europe, provide opportunities for developing and sharing common software and hardware tools, and enable timely diffusion of generated knowledge within the research community. OPTICWISE will therefore serve as a key scheme in the orchestration of OWC research efforts carried out in several European institutions and will be the main enabler for the development of future-generation OWC systems.

Through the effective use of dissemination tools and active participation of its members at different standards bodies and international forums (See Section H), OPTICWISE aims to maintain high external visibility and serve as an internationally recognized reference point in OWC field for both specialists and the general public. The Action will invest in training graduate students and ESRs in order to equip them with the necessary knowledge and skills to contribute in future to this field. Moreover, the Action will foster participation of scientists and researchers from other institutions and programmes by the means of organising workshops/conferences and through various dissemination activities described in Section H.

C.4 Potential impact of the Action

With the emerging bandwidth-hungry services and applications along with the continuous increase in user numbers, it is apparent that the wireless industry needs to develop radical and unconventional ways to stay ahead of this ever-increasing demand. Wireless transmission via optical carriers has the potential to transform the wireless industry. So far, OWC's market penetration has been very limited (with the exception of the WPAN market in which IrDA became a highly successful wireless short-range transmission solution) and OWC technology is considered "niche" by many in other market segments. With the growing number of companies offering terrestrial OWC links in recent years and the emergence of VLC products, the market has begun to show future promise.

In common with other technologies, further growth of OWC depends on successfully addressing end-user problems, techno-economic issues, and developments in constituent component technologies. OPTICWISE will provide the opportunity for a “clean-slate” framework for wireless transmissions and the freedom to propose solutions that are truly radical and are not restricted by the conventional thinking, corporate policy considerations, competition among participants etc. The bottom-up approach of the COST Actions as well as the flexible collaborative spirit of the forum offers the opportunity for innovative idea creation, information flow and result generation covering a variety of topics spanning from fundamental to the applied research. OPTICWISE will therefore significantly contribute to technical knowledge and understanding of OWC systems, propose state-of-the-art OWC methods, models, techniques, strategies and tools through collaborative research activities, and help establish OWC as a mature technology to address the needs of future-generation heterogeneous networks.

The OWC technology offering a truly broadband and cost-effective communication network infrastructure will open up new business opportunities for telecommunication companies. An ultra-high-bandwidth access network with a vast unregulated spectrum will allow the coexistence of many companies offering these services, reinforcing the competition and leading to low prices for the individual subscribers. OPTICWISE will open a path towards the stimulation of economic activity at a pan-European level. The know-how gained from the OPTICWISE Action will facilitate EU industry involvement in all aspects of the OWC field and, in particular, the industrial partners of this Action helping them occupy a leading position in this emerging market among their competitors at a global level.

C.5 Target groups/end users

The target groups of OPTICWISE include academics, researchers, practitioners, industry executives, national or supra-national regulation authorities, standards bodies and the general public. Major stakeholders were involved in the preparation of this Action to carefully identify the objectives and increase the impact of outcomes. For instance, OPTICWISE includes members from industry that will enable interaction between the academia and industry, maintain focus and relevance to the industry interests, and facilitate subsequent technology transfer. Some participants of OPTICWISE are active members in relevant standards bodies and some serve as Officers in governmental bodies. These will provide the opportunity to publicize the findings and recommendations of the Action and influence the decision makers. Since the wireless communication is an indispensible part of everyday life, media (e.g., scientific and non-scientific press) and the general public will also have an interest in the Action outcomes.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The scientific focus of OPTICWISE is to explore and develop novel methods, models, techniques, strategies and tools in infrared, visible and ultraviolet spectral bands that will facilitate the implementation of state-of-the-art OWC systems for future generations of heterogeneous wireless communication networks. Towards this overall purpose, the major research tasks of OPTICWISE have been identified as:

- To develop comprehensive channel models for a wide range of aforementioned applications (See Section B) which capture the physical properties of the underlying infrared/visible light/ultraviolet OWC channel in a realistic yet mathematically tractable manner;
- To elaborate a unified information-theoretical framework, relying on the proposed channel models, to determine the ultimate performance boundaries of OWC systems;
- To develop advanced signal processing, modulation, coding, diversity and coherent/non-coherent detection techniques for the physical layer design of single-input single-output (SISO) OWC transceivers;

- To extend and develop new analytical and algorithmic methods for OWC systems applying the principles of multi-input multi-output (MIMO) systems, cooperative (i.e., relay-assisted), multicarrier and adaptive communications originally proposed in the context of wireless RF systems;
- To investigate upper layer protocols addressing the design of centralized and distributed OWC networks, topology control, routing, multiple access, quality of service (QoS) management, cross-layer optimization, channel-aware packet scheduling, fault detection, avoidance and recovery mechanisms;
- To explore the co-existence and interoperability of OWC with other communication networks;
- To develop innovative tools for efficient design, fabrication and characterization of state-of-the-art opto-electronic and photonic components for OWC systems;
- To develop OWC prototypes for the envisaged applications to test and verify the proposed techniques and algorithms in real-life environments.

D.2 Scientific work plan - methods and means

To carry out the major research tasks defined above in an efficient, focused and coordinated manner, we have identified four Working Groups (WGs) that complement one another. These WGs are WG1 - Propagation Modelling and Channel Characterization; WG2 - Physical Layer Algorithm Design and Verification; WG3 - Networking Protocols; WG4 - Advanced Photonic Components which are elaborated as follows:

D.2.a. WG1-Propagation Modelling and Channel Characterization

The ideal synergy between the algorithm and hardware implementation for OWC systems is usually hampered by their routinely unconnected developments, each typically designed whilst accounting for little of the other’s attributes. One reason for this “left-hand-knows-not-what-the-right-hand-does” predicament is the lack of availability of mathematically plain descriptions for the combined effects of optical wave propagation through the unguided media and the non-ideal constraints imposed by devices and circuit components.

The first step in OWC system design, which will be dealt by WG1, is therefore to develop, evaluate and validate statistical and empirical channel models for indoor and outdoor applications which capture the physical properties of the underlying OWC channel in a realistic manner, but yet still provide mathematically tractability. Towards this overall purpose, the major tasks of WG1 have been defined as

- Microphysical and thermodynamic characterization of rain, snow, fog, haze, clouds and the development of advanced empirical models and tools to evaluate and predict the effect of such meteorological phenomena on the outdoor links;
- Development of novel physical-statistical models for SISO, MIMO and relay-assisted outdoor channels based on wave perturbation method and radiative transfer theory, taking into account the effects of both turbulence-induced fading (i.e., scintillation) and scattering/absorption due to atmospheric aerosols/hydrometeors;
- Development and evaluation of statistical models for mobile links, e.g., aeronautical, vehicular systems;
- Comparative evaluation of infrared, visible light and ultraviolet spectral bands and recommendation of the ones which are least effected by meteorological phenomena;
- Development of hybrid communication channel models where OWC is combined with microwave and/or millimetre-wave links;
- Development of "effective" channel models incorporating the device imperfections (e.g., non-linearities of off-the-shelf transmitter/receivers, receiver sensitivity, beam divergence, etc.);
- Experimental validation of the developed channel models through field measurements combined with meteorological and environmental data and analysis of related channel/link parameters such as atmospheric visibility, scintillation index, Fried parameter, intensity coherence length, etc.;
- Investigation of different beam shape and types (i.e., sinusoidal-Gaussian, annular, dark hollow, flat-topped Gaussian, off-axis-Gaussian and higher order) and quantification of their robustness in different propagation media;
- Development of low-complexity yet highly accurate ray-tracing models for indoor channels under various transmitter and receiver configurations.

D.2.b. WG2- Physical Layer Algorithm Design and Verification

WG2 will explore the fundamental performance bounds of OWC systems, identify the optimum criteria for system design/optimization in light of these, and propose efficient physical (PHY) layer solutions to approach the ultimate performance limits under practical constraints. WG2 will first elaborate an information and communication theoretical framework utilizing the statistical OWC channel models (some of which are already available in the literature and some others to be developed by WG1). This involves the development of mathematical expressions for mutual information, ergodic/outage capacities, diversity-multiplexing trade-off performance and derivation of error rate and outage performance bounds under various channel state assumptions at the transmitter and receiver side assuming different noise regimes (i.e., Gaussian, Poisson, Webb etc.) and turbulence/meteorological conditions (for outdoor applications). Besides being a performance evaluation tool, information and communication theoretic results are invaluable to identify the design space and determine the optimum design criteria for PHY layer techniques to be deployed.

Within the last decade or so, several exciting developments have been witnessed in the area of PHY layer research for wireless communications, most notably the introduction of MIMO communication, cooperative diversity, and novel channel codes along with the proliferation of adaptive transmission and multicarrier communication techniques. Some of these innovative approaches have already been incorporated in international wireless standards and turned into commercial wireless RF products. Such PHY layer methods and techniques have an enormous potential for optimum OWC system design enabling robust and reliable links with higher throughputs, but yet largely unexplored for deployment in optical spectral bands. WG2 will address these issues by developing:

- MIMO OWC systems to exploit transmit/receive, angular diversities and/or spatial multiplexing gains;
- Decode-and-forward and amplify-and-forward relay-assisted OWC systems to take advantage of spatial (cooperative) diversity in a distributed manner, e.g., sensor networks in which MIMO deployments are not possible due to space and power constraints;
- Adaptive OWC transmission schemes in which one or more transmission parameters (such as modulation size, coding type, power, wavelength, beam divergence and shape) are changed based on channel conditions and associated channel sounding/estimation techniques;
- Sophisticated and high-performance channel code families such as turbo codes, low density parity check codes and fountain codes specifically optimized for OWC channels;
- Single-carrier transmission techniques with judiciously designed time- and frequency-domain equalizers for indoor NLOS infrared/visible light OWC systems to mitigate multipath-induced inter-symbol interference;
- Multicarrier communication techniques, e.g. orthogonal frequency division multiplexing (OFDM), as an alternative low-complexity robust solution in multipath indoor OWC channels;
- Hybrid RF/OWC outdoor systems with “soft switching” capability to simultaneously leverage the media and spatial diversities for weather-robust performance in the presence of fog, snow and rain;
- Sequence detection techniques optimal in maximum-likelihood sense to exploit the received signals’ correlation in time and/or frequency domain for robust detection;
- Coherent modulation and detection techniques for longer term market needs;
- "Green" PHY approaches for optimal trade-offs between performance requirements and energy consumption;
- Novel transmission techniques for all-optical packet and burst switching.

Proposed systems will be extensively evaluated through computer simulations under various channel and noise regimes for the intended application scenarios. The impact of practical issues such as device imperfections (e.g., non-linearities of off-the-shelf transmitter/receivers, receiver sensitivity, beam divergence, etc.) and environmental conditions (e.g., building sway, alignment problems, adverse weather conditions in outdoor systems) on system performance will be carefully investigated. Given the availability of experimental test-beds and advanced measurement equipment at the participating institutions, OPTICWISE will further have the opportunity to implement the proposed PHY algorithms and methods and test them under real-life conditions for validation purposes.

D.2.c. WG3-Networking Protocols

While WG2 focuses on PHY layer for point-to-point transmission, WG3 will deal with upper layer protocol stacks as well as investigating co-existence and interoperability of OWC with other communication networks. The activities within WG3 can be grouped into two main categories targeting long-range (i.e., on the order of kilometres) and short/medium-range (i.e., up to a few tens of metres) OWC networks elaborated in the following.

Experimental studies by the participants of this Action have recently demonstrated the successful deployment of dense wavelength division multiplexing (DWDM) in point-to-point terrestrial OWC links. This has resulted in the realization of aggregate speeds at the order of Terabits per second (Tb/s) for outdoor systems. Building on these promising results, WG3 considers a wide-area outdoor OWC ultra-broadband network which consists of a set of geographically distributed transceiver nodes and atmospheric links interconnecting the nodes. Due to OWC's inherently different link nature and spatially confined electromagnetic transmission, traditional networking protocols developed either for wired networks or wireless RF networks are not applicable to degree-constrained and highly dynamic OWC networks. WG3 will fill out this significant research gap by developing

- Advanced automatic repeat request (ARQ) algorithms with an incremental redundancy for improved link layer performance;

- Multiple access techniques based on the available spatial, temporal, wavelength and code dimensions;
- Cross-layer designs and channel-aware packet scheduling algorithms to exploit multiuser diversity;
- Dynamic and autonomous topology control schemes for proactive reconfiguration (both in software and hardware) of the OWC network in response to changes in atmospheric and traffic conditions and user demands;
- Agile routing and wavelength assignment algorithms with optimized performance metrics (i.e., end-to-end delay, throughput, QoS) assuming different networking architectures such as optical circuit switching (OCS), optical burst switching (OBS) and optical packet switching (OPS);
- Fault detection, avoidance and recovery strategies required for harnessing the continuity of service provisioning in a fault-susceptible network environment.

For short/medium-range communications, the focus of the WG3 will be on the design of OWC-based WLANs, WPANs and WBANs, covering ranges from a few tens of metres down to sub-metre communications. The latest commercially available products have already entered the Gigabits/second (Gb/s) regime, e.g., Giga-IR from IrDA enables personal OWC at 1.25 Gb/s. The optimal utilization of this unprecedented capacity calls for a detailed study and innovative extension of available protocol stacks along with novel optimized designs. Specific research areas will be

- Evaluation and individual optimization of Giga-IR protocols such as OBEX (Object exchange protocol), TTP (Tiny transport protocol), IrLMP (Infrared link management protocol), IrLAP (Infrared link access protocol);
- Identification of protocol interactions that affect the stack performance in Giga-IR and cross-layer optimizations;
- Design of novel and robust admission control, multiple-access, and interference management techniques for cellular OWC WLAN networks;
- Routing algorithms and range optimization for VLC-based vehicle-to-vehicle networks.

WG3 will further investigate the co-existence and interoperability of OWC with other communication technologies and networks and develop heterogeneous network architectures to optimally utilize the potential of OWC.

D.2.d. WG4-Advanced Photonic Components

The successful implementation of OWC systems and indeed the research activities highlighted in the previous WGs are premised on the availability of suitable and appropriate optoelectronic/optical front-end devices and components. There is therefore a compelling need for a scientific approach to determine what components/devices are most appropriate, select the most suitable operating conditions and parameters of the device, and design new components/sub-systems that will satisfy the inherent needs of OWC systems. These scientific research activities form the central theme of this WG4. The goals within the WG4 have been therefore defined as follows:

- Investigation of OWC wavelength selection for terrestrial and indoor applications, with emphasis on factors such as absorption, scattering, eye and skin safety, divergence loss, cost, availability of source and photodetector combinations among other trade-offs. Wavelength conversion technologies will also be examined as a means of improving receiver sensitivity.
- Contribution to a comprehensive modelling effort to understand how device trade-offs contribute to system performance. This will provide a foundation for specific component development efforts.
- Investigation and subsequent design of large area photodetectors with a low capacitance (2-10 picofarads) needed to unlock the huge bandwidth potential of OWC systems. Such low capacitance detectors are especially required for larger wavelengths in the micrometre range. The optical power collected at the receiver is proportional to the photodetector surface area, and large area photodetectors are known to have a low bandwidth due to their high capacitance. Thus preamplifier designs that are tolerant to this capacitance as well as receivers with optimised concentrating optics are essential, and these are not commercially available. For very high speed OWC links in the range of Gb/s, multi-array transmitters and receivers are one option to provide full coverage area, mobility, reduced ambient noise, high bandwidth and performance.
- Design and development of highly sensitive optical receiver with optical amplifiers - fibre or semiconductor - in intensity modulation/direct detection systems. This will also include the design and production of novel optical antennas, photonic devices and subsystems, especially for receiver-amplifier modules.

- Design and implementation of liquid crystal-based beam steering techniques which could lead to improved angular diversity and tracking in OWC link.
- Integration of the optoelectronic and electronics at substrate levels, thus offering low inductance and capacitance, good thermal management and simplification of packaging.
- Integration of analogue and digital technologies to improve speed and reduce the noise and development of high-speed FPGA and ASIC technology together with the deep memory for implementation of sophisticated and high-performance coding algorithms.
- Investigation of a combination of tracking transmitters and tracking receivers with the potential to maximise the power available at the receiver.
- Design and development of various OWC subsystem/system test-beds at visible, infrared and ultraviolet wavelengths for indoor and outdoor applications.
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The research activities of WG4 will contribute to have a clear roadmap for future devices/component/sub-system development together with the expected improvements in the OWC system performance.

E. ORGANISATION

E.1 Coordination and organisation

This Action brings together more than 50 researchers from European academic and research institutions, government bodies and companies who are involved in different aspects of OWC research supported by national and EU research grants. Through its envisioned activities, OPTICWISE will provide linkages among these European research groups thus overcoming the current fragmentation. The organisation of OPTICWISE will follow rules and regulations set by COST guidelines to be applied in the Action specific way as appropriate. The Action will be administered by a Management Committee (MC) which consists of two representatives from each COST country and one representative for each non-COST institution admitted to participate in the Action (up to two such representatives from each non-COST country). The MC will meet, as a rule, twice a year in different countries taking part in the Action. The agenda of each MC meeting will include an item dedicated to the milestones to be achieved in the next year, including organisation of next meetings, training schools, workshops and other activities.

The communication in the periods between the MC meetings will be held exclusively by electronic means such as e-mail and video-conferencing. The Action will set up e-mail communication lists and a dedicated website that will be regularly updated.

The MC Chairperson and the MC Vice-Chairperson, who will be responsible for day-to-day management of the Action, will be elected by the MC at the kick-off meeting through majority vote. The MC Chairperson will act as intermediary between the MC and the COST Office, be responsible for the preparation of annual scientific reports, and ensure the overall progress of Action as planned in the signed Memorandum of Understanding. In close coordination with the Chairperson, the Vice-Chairperson will be responsible for annual financial reports, carry out the logistics of MC meetings, together with the local organizer and will manage the organization of training activities, dissemination events and liaisons with other projects. A Steering Committee (SC) will be defined which consists of MC Chairperson, MC Vice-Chairperson and Chairs of the four WGs. The SC will ensure smooth and dynamic management of the events that will take place between two consecutive MC meetings. The MC Chairperson will report all decisions taken by the SC at the next MC meeting.

For maintaining research focus and tight collaboration, four topical WGs have been defined which complement one another (See Section D). A permanent Special Interest Group (SIG) entitled "Techno-Economics, Industrial Standards and Future Trends in OWC" will be formed. This will be focused on leading trends in emerging OWC applications and educating and influencing decision makers at all levels of the OWC market chain. Based on the needs and technical development trends, other SIGs will be further created addressing specific applications. WG and SIG meetings will take place in conjunction with MC meetings to minimize travel costs. Organization details and interaction among WGs and SIGs are provided in Section E.2. To ensure a proper monitoring and evaluation of the achievement of objectives, WG and SIG Chairpersons will provide semi-annual reports to the MC.

Besides MC and WG meetings, a workshop on a selected theme of the Action will be organized each year. In conjunction with these workshops, training schools, tutorials and short courses will be organized on OWC fundamentals and emerging topics. These will be delivered by leading experts in the field including invited distinguished speakers from outside the Action. A conference dedicated to OWC will be organized in the fourth year of the Action. The Action will also provide funding for Short-Term Scientific Missions (STSMs). The objective of the missions is to promote joint work between research groups and bridge the technology and know-how gap of collaborating labs during the short research stays.

E.2 Working Groups

OPTICWISE will involve four WGs whose scientific scopes have been already elaborated in the Section D. At its first meeting, the MC will appoint a Chairperson and a Vice-chairperson for each WG. Each WG Chairperson will be responsible for setting goals and milestones and for reporting their achievements to the MC based on the predefined timetable (decided at MC meetings). Depending on the evolution of the work, Sub-Working Groups (SWGs) will be organized to enable a better and faster achievement of results within the time scale of the Action. For example, in WG1 “Propagation Modelling and Channel Characterization”, up to three SWGs might be created to address issues in the propagation phenomena in infrared, visible light and ultraviolet spectral bands with distinct characteristics.

Based on the needs and technical development trends, SIGs will be created addressing specific applications (e.g., ultraviolet sensor networks, VLC-based vehicular communications, underwater optical communication, mobile OWC etc.) and involve members from more than one WG. These SIGs will be created by the MC following a bottom-up approach and could be permanent or temporary depending on the researchers’ interests and development trends.

The only permanent SIG will be "Techno-Economics, Industrial Standards and Future Trends in OWC". This SIG aims to focus on business and market issues related to OWC in order to understand the impact of this communication technology on the next generation inclusive society. The study as well as the active participation to international standard bodies like ITU (International Telecommunication Union), ETSI (European Telecommunications Standards Institute) or FSAN (Full Service Access Network) through this SIG will help in addressing the industrial needs. Different scenarios regarding the realization of future generation network infrastructures and their subsequent socio-economic impact will be investigated by merging and coordinating the works of the WGs with the Action.

E.3 Liaison and interaction with other research programmes

Cooperation with other existing European and international research programmes dealing with related topics will be actively pursued. OPTICWISE has already established contact with the COST Action IC0802 most of whose members in WG3 are also involved in this Action. The Action will further interact with COST Actions TD1001 (Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications), IC0803 (RF/Microwave Communication Subsystems for Emerging Wireless Technologies) and FP7 projects NEXPRESSO (Network for Exchange and Prototype Evaluation of Photonics Components and Optical Systems), PLATON (Merging Plasmonic and Silicon Photonics Technology towards Tb/s routing in optical interconnects), C-3PO (Colourless and Coolerless Components for low Power Optical Networks), ACCORDANCE (A converged copper-optical-radio OFDMA-based access network with high capacity and flexibility) and SatNExIII (European Satellite Communications Network of Excellence). These will be established by personal contacts in the first instances. The members of the proposed Action that already are members of the other programmes will serve as the primary contact point for establishing the initial contacts. The MC through relevant WGs will pursue to expand contacts by inviting scientists from other COST Actions and FP7 projects to participate in the workshops and other dissemination activities such as seminars, tutorials and short courses. OPTICWISE will also maintain links with international research programmes and centres including, but not limited to, Canadian Institute for Photonic Innovations (CIPI), NSF Centre on Optical Wireless Applications in Imaging, Communications, Networking, and Navigation Systems (lead by the Pennsylvania State University, USA), and Smart Lighting Engineering Research Centre (lead by the Boston University, USA).

E.4 Gender balance and involvement of early-stage researchers

Involvement of female researchers and ESRs at all levels will be actively encouraged including their active participation in meetings, conferences and workshops to be organized in the frame of this Action. In the election process for executive positions, female researchers will be particularly encouraged for nomination. Travel grants will be allocated for female researchers to attend the annual SPIE Women in Optics networking activity. Female researchers active in the area of OWC will be endorsed by OPTICWISE for IEEE, SPIE and other professional awards and recognitions. Vice-Chair positions in WGs will be exclusively allocated for candidates among ESRs. In the selection process of STSMs, priority will be given to ESRs. Because such missions are particularly important for young researchers and invaluable to create a scientific formation of highly open-minded attitude, not bounded to the home jargon, used to travel and to interact with different groups, and capable of understanding and solving problems lying at the frontier of different disciplines. Another incentive for ESR involvement will be a best paper award exclusively targeted for ESRs at the annual workshop of the Action.

F. TIMETABLE

The duration of this Action is four years. At the kick-off MC meeting, WGs and SIGs will be formed and executive positions in MC, WG and SIGs will be filled. The website and e-mail communication lists will be launched at latest within three months of the kick-off meeting. Two MC meetings will take place each year. WG and SIG meetings will take place in conjunction with MC meetings. The activities within each WG will be carried out to realize the major milestones under the following tentative timescale:

- Updated literature survey and development of common reference scenarios to allow better comparability of results (**Duration:** Six months starting at kick-off meeting denoted by T0);
- Identification and selection of the most promising techniques to be investigated and evaluated in detail (**Duration:** Six months starting at kick-off meeting denoted by T0);
- Development of methods, models, techniques, strategies and tools for the areas under consideration, and realization of simulations and measurements (**Duration:** Three years and a half, starting at T0+6 months);

- Assessment of developed methods, models, techniques, strategies and tools and comparison with state-of-the-art under common reference scenarios (**Duration:** Three years starting at T0+12 months under the assumption that initial results have been obtained as early as in a 6-month span).
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Each WG Chairperson will submit semi-annual progress reports. MC Chairperson will prepare annual scientific reports for the overall activities of the Action. The Final Report, which will be delivered at the end of the fourth year, will be prepared according to a continuous process of monitoring and identification of the most relevant results obtained. However, the most significant effort for its preparation will be carried out within the last year of the Action. The Action will organize an annual workshop in the first three years and a large conference in the last year of the Action. Organizations of such events will be planned at MC meetings preceding the event allowing at least 6 months of preparation.

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, BE, CZ, DE, EL, ES, FR, IL, IT, PT, TR, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at EUR 48 Million for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The targeted audience of OPTICWISE includes a wide range of potential beneficiaries ranging from OWC researchers to the general public. Researchers active in the field of OWC based in academia, research institutions or the industry will benefit from the high-quality research results produced within this Action. Additionally, researchers in other disciplines dealing with atmospheric physics, information/ communication theory, electromagnetic propagation theory, wireless communications, networking, photonics, optical communications, and quantum optics will be among the targeted audience of this Action. Through its findings and recommendations, the Action aims to increase awareness on OWC at all levels of the OWC market chain including European level policy makers, government (national) policy makers, standards bodies, manufacturers, service providers and last but not least, general public as end-users.

H.2 What?

Effective information dissemination is a key factor for the success of a multinational, collaborative research effort. The Action will utilize a wide array of dissemination tools to reach its targeted audiences. These include

- Online tools (Public website, e-mail communication lists, participation in internet forums and professional network sites),
- Publications (Articles, surveys and tutorials in peer-reviewed technical journals, conference papers, interim reports, white papers, book chapters, books, special issues in journals etc.),
- Printed/online non-technical material (Leaflets, newsletters),
- Organization of and participation in technical events (Workshops, seminars and conferences to be organized by the MC, contributions to other national and international conferences, symposia and workshops),
- Teaching activities,
- Participation in standards bodies and international forums.

H.3 How?

Online Tools: A website for OPTICWISE will be launched within three months of the start of the Action. It will provide general information on OWC understandable for the non-specialised audience, present latest news, information and developments in regard to the Action, allow the OWC research community to gain access to state-of-the-art technical material (e.g., surveys, tutorials, research publications, software tools etc.) prepared by the Action's participants and further facilitate communication exchange within the Action. Specific content of the website will be: (a) General information about OPTICWISE including background, objectives, scientific programme and organizational aspects, (b) Contact information for the Action participants, (c) Publications produced within the Action, (d) Announcements on the Action events such as MC meetings, seminars, workshops, conferences, (e) Announcements on Action-related activities such as STSM calls, open student/researcher positions in participating institutions, (f) General information on OWC understandable for non-specialists, (g) Online survey/tutorial papers, research papers and software tools for OWC research community, (h) Teaching tools (e.g., slides and video recording of seminars and short courses offered by distinguished speakers, etc.), (i) Links to websites of the researchers and companies active in OWC outside of the Action and websites of related FP7, COST and other national/international projects, (j) Calendar for OWC related workshops, symposium, conferences, (k) Password protected part of website for information exchange among participants (e.g., working documents).

While the website serves as the front face of the Action, other online tools will be effectively utilized for dissemination purposes. E-mail communication lists will be established at different levels. One will be for the general public, policy makers and scientists not directly involved in OPTICWISE, but who indicate their interest through the website to be informed. The main purpose of this e-mail list will be to periodically (every 6 months) update the recipients with the latest developments regarding the Action and direct them to relevant articles or news in the web regarding these developments. The other e-mail lists will be geared towards to facilitate communication and discussions among MC, WG and SIG members. The Action will also participate in professional network sites (e.g., LinkedIn) and engineering internet forums in an effort to increase public awareness.

Publications: A main dissemination channel of OPTICWISE will be publications in peer-reviewed archival technical and scientific journals as well as in conference proceedings. These publications include research articles, surveys and tutorials to be produced as a result of the Action participants' research activities within WGs and SIGs. In some cases, interim reports will be produced for timely dissemination of novel results to avoid delays with publication process. During the Action, two special issues on OWC will be prepared for leading journals. An edited book on OWC will be published at the end of the Action. The MC will promote co-publications as much as possible and will motivate participants to publish joint research results. Whenever possible, participants will be encouraged to highlight their research findings in mass media to increase public attention.

Printed/online non-technical material: At the start of the Action, a leaflet will be created to introduce the OPTICWISE project and to disseminate its main objectives. The leaflet will be made available for download on the OPTICWISE website and printed copies will be distributed at events (e.g., conferences, workshops, etc.) where the participants of the Action will attend. The information provided in the leaflet will be high-level and address both specialists and non-specialists. A semi-annual newsletter will be prepared highlighting the latest achievements and public deliverables of the Action. It will be made available both as softcopy (for download at the website) and hardcopy (for distribution at the related events).

Organization of, and participation in, technical events: The Action will organize a workshop on a selected theme each year and a final conference in the fourth year of the Action. These workshops and the conference will be open to all researchers. Panels will be organized during these workshops to discuss the future trends in OWC with the participation of researchers, interested private and public bodies and stakeholders (policy makers and legislation/administration officers) at both national and European levels. OPTICWISE members will attend international conferences (e.g., IEEE, SPIE) to present their latest research results. Furthermore, efforts to organize additional OWC symposium/workshops under OPTICWISE leadership in prestigious international conferences will be actively pursued.

Teaching activities: The Action will make available online teaching material such as survey/tutorial papers and software tools developed by OPTICWISE members. In conjunction with annual workshops, training schools will be held and tutorials and short courses will be delivered by leading experts (including invited distinguished speakers from outside the Action network) on OWC fundamentals and emerging topics.

Participation in standards bodies and international forums: OWC related standardization efforts include IrDA, ISO - CALM (International Organization for Standardization - Communications Access for Land Mobiles), Visible Light Communications Consortium (VLCC), IEEE 802.11 IR, IEEE 802.15.7 and Study Groups 3 and 9 of ITU-R (International Telecommunication Union - Radiocommunication Sector). Some participants of OPTICWISE are already active members in relevant standard bodies that will provide the opportunity to influence and publicize the findings and recommendations of the Action. Furthermore, the Action will participate in selected international forums that shape the future of wireless systems, such as the WWRF (Wireless World Research Forum) and Photonics21 to which some of OPTICWISE members have already contributed in the past and will actively participate during the Action.