TeMA

Journal of
Land Use, Mobility and Environment

This special issue collects a selection of peer-review papers presented at the 8th International Conference INPUT 2014 titled "Smart City: planning for energy, transportation and sustainability of urban systems", held on 4-6 June in Naples, Italy. The issue includes recent developments on the theme of relationship between innovation and city management and planning.

Tema is the Journal of Land use, Mobility and Environment and offers papers with a unified approach to planning and mobility. TeMA Journal has also received the Sparc Europe Seal of Open Access Journals released by Scholarly Publishing and Academic Resources Coalition (SPARC Europe) and the Directory of Open Access Journals (DOAJ).

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SMART CITY

PLANNING FOR ENERGY, TRANSPORTATION AND SUSTAINABILITY OF THE URBAN SYSTEM

Special Issue, June 2014

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TeMA. Journal of Land Use, Mobility and Environment offers researches, applications and contributions with a unified approach to planning and mobility and publishes original inter-disciplinary papers on the interaction of transport, land use and environment. Domains include engineering, planning, modeling, behavior, economics, geography, regional science, sociology, architecture and design, network science, and complex systems.

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Journal of
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This special issue of TeMA collects the papers presented at the 8th International Conference INPUT 2014 which will take place in Naples from 4th to 6th June. The Conference focuses on one of the central topics within the urban studies debate and combines, in a new perspective, researches concerning the relationship between innovation and management of city changing.

TeMA Journal of Land Use, Mobility and Environment

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EIGHTH INTERNATIONAL CONFERENCE INPUT 2014

SMART CITY. PLANNING FOR ENERGY, TRANSPORTATION AND SUSTAINABILITY OF THE URBAN SYSTEM

This special issue of TeMA collects the papers presented at the Eighth International Conference INPUT, 2014, titled "Smart City. Planning for energy, transportation and sustainability of the urban system" that takes place in Naples from 4 to 6 of June 2014.

INPUT (Innovation in Urban Planning and Territorial) consists of an informal group/network of academic researchers Italians and foreigners working in several areas related to urban and territorial planning. Starting from the first conference, held in Venice in 1999, INPUT has represented an opportunity to reflect on the use of Information and Communication Technologies (ICTs) as key planning support tools. The theme of the eighth conference focuses on one of the most topical debate of urban studies that combines , in a new perspective, researches concerning the relationship between innovation (technological, methodological, of process etc..) and the management of the changes of the city. The Smart City is also currently the most investigated subject by TeMA that with this number is intended to provide a broad overview of the research activities currently in place in Italy and a number of European countries. Naples, with its tradition of studies in this particular research field, represents the best place to review progress on what is being done and try to identify some structural elements of a planning approach.

Furthermore the conference has represented the ideal space of mind comparison and ideas exchanging about a number of topics like: planning support systems, models to geo-design, qualitative cognitive models and formal ontologies, smart mobility and urban transport, Visualization and spatial perception in urban planning innovative processes for urban regeneration, smart city and smart citizen, the Smart Energy Master project, urban entropy and evaluation in urban planning, etc..

The conference INPUT Naples 2014 were sent 84 papers, through a computerized procedure using the website www.input2014.it . The papers were subjected to a series of monitoring and control operations. The first fundamental phase saw the submission of the papers to reviewers. To enable a blind procedure the papers have been checked in advance, in order to eliminate any reference to the authors. The review was carried out on a form set up by the local scientific committee. The review forms received were sent to the authors who have adapted the papers, in a more or less extensive way, on the base of the received comments. At this point (third stage), the new version of the paper was subjected to control for to standardize the content to the layout required for the publication within TeMA. In parallel, the Local Scientific Committee, along with the Editorial Board of the magazine, has provided to the technical operation on the site TeMA (insertion of data for the indexing and insertion of pdf version of the papers). In the light of the time's shortness and of the high number of contributions the Local Scientific Committee decided to publish the papers by applying some simplifies compared with the normal procedures used by TeMA. Specifically:

- Each paper was equipped with cover, TeMA Editorial Advisory Board, INPUT Scientific Committee, introductory page of INPUT 2014 and summary;
- Summary and sorting of the papers are in alphabetical order, based on the surname of the first author;
- Each paper is indexed with own DOI codex which can be found in the electronic version on TeMA website (www.tema.unina.it). The codex is not present on the pdf version of the papers.

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SPECIAL ISSUE

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Smart City - Planning for Energy, Transportation and Sustainability of the Urban System

Naples, 4-6 June 2014

LI-FI FOR A DIGITAL URBAN INFRASTRUCTURE

A NOVEL TECHNOLOGY FOR THE SMART CITY

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ABSTRACT

The process of "building a smart city" implies that the way a urban area provides its traditional functions be properly re-designed, in order to meet the often conflicting requirements of furthering the economical development and of improving the quality of the life. ICT can make available methodologies and tools able to support such process, as far as the new solutions are carried out within a global vision of the task to be carried out i.e. within a system approach.

In such context, even traditional infrastructures as the streetlamp system of a city can reveal interesting opportunities, when coupled with updated technologies. Here, the potential benefits of moving to the LED technologies are presented. The relevance of Li-Fi technology is pinpointed. in relation to the ability of efficiently install wireless links for data transfer without increasing (or also reducing) the microwave background in a urban area.

Also the data collection can be improved leveraging upon the already installed streetlamps: the ever increasing amount of sensors (required for many functions, from street security to environment protection) can be deployed without further waste of urban 3D space.

KEYWORDS

Li-Fi, Sensors, Smart cities, Urban environment.

1 INTRODUCTION

"Smart city" is a concept practically ubiquitous in the scientific literature. This is a clear signal of interdisciplinary nature of the related researches, ranging from urban planning to ICT applications and to new hardware systems (sensors, processors, etc.).

Such relevance basically derives from the following points:

- the urban areas are steadily and quickly expanding, because they are able attract and include both people and economic activities;
- some estimates indicate that by 2030 urban areas will globally host about 5 billion people (UNFPA, 2007); out of a foreseen world population of about 8.4 billion, the share of urbanized population will be in the range 78% to 85% in America and in Europe while 48% to 55% in Africa and in Asia, as shown in Fig. 1 (UNDESA, 2012; UNDESA, 2013);
- on the basis of such estimates, the urban population will grow by 100% in Africa and Asia during the time interval from 2000 to 2030, even if the rate of urbanization is steadily declining in every region since 1960; the governance of the city has to meet new challenges at unprecedented quantitative and qualitative scales (UNFPA, 2007);
- among such challenges, the most relevant ones appear to be those related to the quality of citizens' life and to the environmental management; any new development in such fields provides significant improvements to the many facets of the urban governance.

As a matter of fact, the urbanization process is two-faced:

- it provides more job opportunities, on the basis of the many relationships that can be established in the city; the economic development has been constantly based upon the enlargement of the urban areas;
- on the other hand, it challenges the social and ecological resilience of the interested areas; the city usually tends to have a footprint greater than the area delimited by its own borders.

The key point is that the city (from the megacities to the small neighborhoods) is a system of systems with its own dynamic features. This implies that any "local" solution has to be designed taking into account the "global" context. Specifically, the deployment of new "smart" solutions both is caused by and impacts upon the evolution of the urban ecosystem in its amplest meaning (Bonomi and Masiero, 2014).

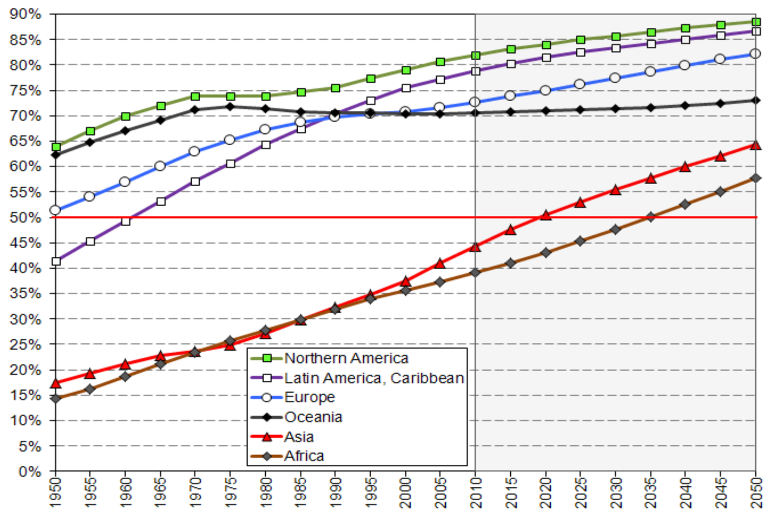

Fig. 1 – Ratio of the urban population to the total population, 1950 - 2050, by major geographical areas

2 SMART CITIES AND ICT

It should be noted that the concept of "smart city" is not completely defined in itself; however, such concept is necessary, in order to correctly evaluate the technological developments (as those here dealt with in the following). The term "smart city" started to show up in the literature in the last quarter of the past century. Since then and up to our days, so many definitions have been suggested that Nam and Pardo (2011) claim the term "smart city" is definitely a fuzzy one. Papa et al. (2013) provide a global review of such definitions, analyzing the scientific literature on an interval of more than thirty years.

Nam and Pardo (2011) aim to set up an operational definition through the observations of the relevant features of what appears to be a "smart city". Basically, they observe that the following factors are necessary for a "smart city":

- technology (infrastructures of hardware and software);
- people (creativity, diversity, and education);
- institution (governance and policy).

It is easy to recognize that such list include all and only the components of an abstract information system, as usually described by IT scholars. A direct link appears to emerge between urban planning and informatics. As well known, ICT is the application side of informatics; from such point of view, ICT is the enabling component of the migration of an urban area to the status of "smart city".

However, in order to establish a smart city (or to recognize an already established one), even if necessary such factors become sufficient if and only if some sort of threshold is reached. Given the interrelationships among the above mentioned factors, a city is "smart" when such factors are able to provide sustainable growth and to improve the quality of the life. Therefore, adopting a systems view (on the basis of the seminal works of Forrester, 1969 and of Mc Loughlin, 1969; the ideas of Batty and Longley, 1994, could also be taken into account), it can be said that in its development the city "diverges" along a new path and evolves to the state of "smart", only if the combined pressure of such ICT-enabled factors is modulated over a certain amount.

Furthering the earlier work of Fistola (2001), namely the vision of *M.E.-tropolis*, Annunziato (2012) suggests a three-level framework for the structural analysis of the "smart city" including:

- *city government*, where the administrative services are made available;
- *city operation*, where the management of the different utility networks is integrated;
- *city life*, where the citizens interact with the administration and access the utility networks.

As far as ICT is referred to as the enabling technology of the "smart city", a special role is given to the data acquisition, to the decision support and to the feedback loops that carry out command and control actions. Specifically, the *city operation* level requires an extensive exploitation of sensors, distributed over the territory of the city and able to provide data flows whose time- and space-frequencies are dictated by the rate of evolution of the urban processes. The information carried by such data fluxes links the citizens' needs (the *city life* level) to the administrative decisions (the *city government* level), improving the global system performance. The sheer amount of data to be collected and processed can be intimidating; accordingly, many R&D efforts have already been devoted to such issue (labeled as "Big Data") and various solutions (often derived by a fruitful cross-fertilization of different scientific sectors) are being available for concrete applications (Manyika et al., 2011). However, it should be noted that the problem has to be dealt with from, at least, two different points of view:

- the data collection from the real world;
- the extraction of the information content from the collected data.

The latter point relies upon the balance of the (steadily decreasing) processing and storage costs vs. the (quickly increasing) available amounts of Big Data. Such balance is mostly carried out in the virtual world (i.e. it mainly involves knowledge) and therefore it is not physically bounded. On the contrary, as far as the involved sensors require physico-chemical interactions, the former point is strongly influenced by the finite amount of available matter and energy, whose eventual shortage will be experienced in the real world and firstly in the urban areas. Moreover, the spatial dimension too is a finite resource in such context. In relation to the ever increasing spectrum of urban processes to be monitored, it cannot be assumed an unlimited proliferation of sensors. The technological efficiency of the sensors appears to be a limiting factor on the path to the "smart city", at least on the medium to long range. Therefore the relevant stakeholders (from city administrators to urban planners and to final users) should be aware of the actual opportunities of deploying "multi-targeted" or "clustered" sensors and, moreover, of embedding such sensors into already existing utility networks. In the following, reference will be made to the urban street lighting, for sake of brevity. However, such reference can be easily extended to other utility networks. Anyway, it should be noted that the ICT-enabled management of the urban street lighting is currently assumed as necessary for the "smart city", aiming to the environmental protection in terms of reduced energy consumption (Gargiulo et al., 2013).

3 NETWORKING THE SMART CITY

In the following, it will be outlined how new streetlamps can improve the life experience in the smart cities of tomorrow. The different lights source technologies (gas, mercury light, sodium light, etc.) adopted in the past have a low energy performance and a long switch on/off time (of the order of minutes) as their a common characteristic. Therefore, R&D efforts have been focused on removing such constraints. US DoE (2013) has analyzed the various light sources, whose capabilities are shown in the following Fig. 2, where the black rectangles represent the efficacy (in terms of lm/W) of conventional lamps or LED packages. The luminaire efficacy (depicted by the shaded regions), refers to the whole system (including electrical, thermal, and optical losses).

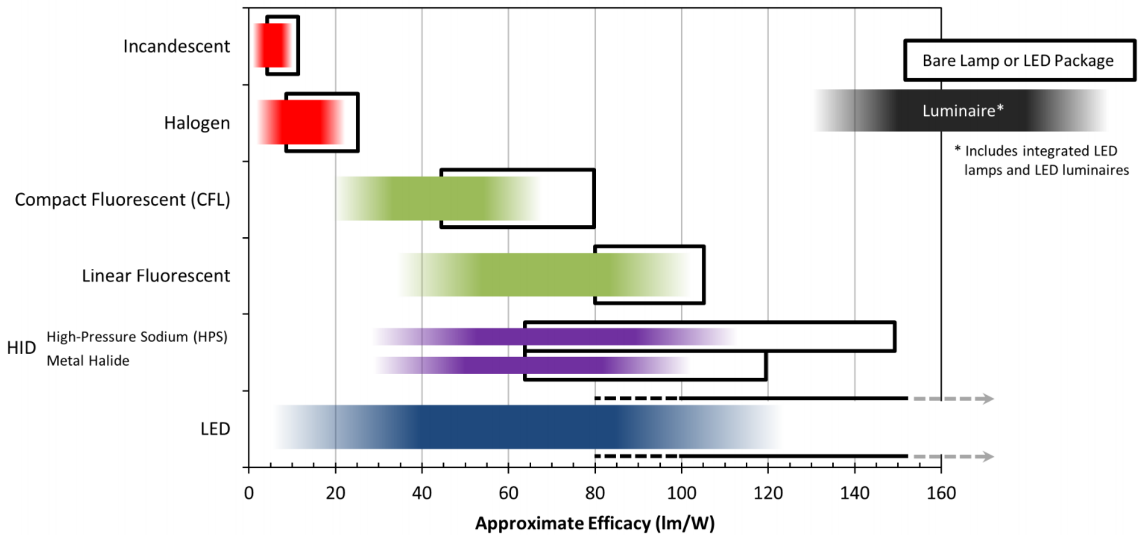

Fig. 2 –Range of efficacy for various light sources.

Among the technologies referred to in Fig. 2, only LED is expected to substantially increase the efficacy in the near future. The forecast of efficiency of white LED lamps has also been investigated by US DoE (2012) in its multi-year Program Plan. It should be noted that white color can be provided relying on two basic approaches: PC (Phosphor Coated) packaged LED and CM (Color Mixed) LED.

In the past years (up to 2005) there weren't differences between CM- and PC- based solutions; the efficacy differences were based on the color temperature. On a 10-year horizon, the CM-based solution will reach more than 250 lm/W and will be the dominant one. It should be noted two interesting features:

- in the past, the efficacy of a LED source was dependent on the color temperature (warm or cool); on the medium term, the efficacy will depend only on the adopted solution (CM or PC);
- for a given color temperature, in the past the efficacy was irrespective of the solution (PC or CM); on the medium term, the best efficacy will be provided by CM.

A LED light source can achieve very short turn on/off time and can be easily dimmed. It is useful to clarify that in the LED technology the flux is assumed to be either absolute or relative. The absolute flux is measured in lumen (lm), according to the international system of units (SI). The relative flux is measured as a ratio of the actual value to a reference value; such reference value is established on the basis of standard conditions: lifelong continuous service, room temperature, forward current intensity, etc. Therefore, the relative flux can achieve values greater than 100%, if the reference conditions are modified.

For instance, a commercial LED lamp (CREE, 2013) has a reference value of 260 lm. Such reference value implies a forward current of about 710 mA and a voltage of 2,9 V. Its voltage can be increased up to 3.35 V, achieving a relative flux of 325% (obviously, this value can be hold for a very short time interval). On the other hand, its voltage can be decreased, up to 2.65, with a corresponding relative flux of 15%.

With a view to signal modulation, it is important to pinpoint that the relative flux is a quasi-linear function of the forward current.

Therefore, the LED lamp shows two characteristics:

- the relative flux is a quasi-linear function of the forward current;
- the relative flux can be modulated over a quite wide range of values.

Those two characteristics, coupled to the other ones (in particular, the short switch time), allow the exploitation of the LED light as an information carrier at *access network* level.

Telecom services are provided by 2 infrastructure levels: *access network* and *core network*. Wireless or radio technology are the best solutions, at *access network* level, to meet the needs of mobile information sharing (of utmost relevance for the "smart city", where the amount and the topology of the users to be connected are always subjected to quick and substantial changes). In the literature, the term *radio* pertains to GSM, UMTS and LTE technologies utilized on distances from 100 m up to 35 km (Pini, 2010) while with the term *wireless* refers to transmissions on distances up to 100 m (as those commonly involved in a urban area). The high-speed links at the *core network* level are mostly provided by optical fibers.

The wireless transmissions usually exploit the frequency bands of 2.4 and 5 GHz of the electromagnetic spectrum. The related wireless technology is based on the IEEE 802.11x set of standards and it is known as Wi-Fi. However, it has to be noted that such frequency bands are heavily accessed, for voice as well as data networking. Therefore, even if many cities have already installed extensive Wi-Fi networks on their territory, such frequency bands can be seen as a quite limited resource, with possible service problems on the medium-to-long term.

Some other solutions, globally referred to as NFC – Near Field Communication, can be of value on the very short distances (Iannucci and Pini, 2013). However, the scarcity of available band has to be globally dealt with. This appears to be feasible by relying on the high spatial resolution of the physical mesh whose nodes are exactly the thousand of streetlamps above mentioned. With such approach, the streetlamps host the wireless access points. Usually, a Wi-Fi technology is exploited; however, as far as the streetlamps are equipped with LED sources, wireless web access points can efficiently be based upon a more novel technology: Li-Fi (Light-Fidelity), whose name was coined in 2011 by Harald Haas of the University of Edinburgh.

Li-Fi is the emergent technology that uses the fast light variations to transmit data, instead of radiofrequencies. From 2012 to 2016 EPSRC, the main UK government agency for funding research and training in engineering and the physical sciences, is devoting 4.6 million GBP to a large project targeting such technology (UP-VLC, 2012).

The light is the portion of the electromagnetic spectrum that can be received directly by human eyes. Its wavelengths range from 380 nm to 760 nm, i.e. a bandwidth from 400 to 790 THz (1 THz = 1000 GHz). Light has been used to transmit information since many centuries, by fire signals and later also by lamps and Morse code. More recently, since the sixties of the past century, light is being used in optical fibers with a bandwidth from 100 Mbps up to 1 Tbps; light is also exploited for point-to-point wireless transmission in LoS (Line of Sight) up to few kilometers using laser-based, stabilized optical systems; the associated costs can often be an issue.

Nowadays, LED lamps have opened a new scenario. LED can achieve a much faster switch on/off time than traditional lamps and this characteristic is compliant with the request of broadcasting solution. LED-based services are available in a fraction of price, weight and volume required by other solutions.

The lesser useful range of LED is not really an issue; on the contrary, when the access points are hosted by the streetlamps (therefore in a high-density mesh) the interferences are much less in Li-Fi than in Wi-Fi. This aspect allows a novel usage of the thousand of streetlamps already installed in each medium-sized city: mainly relying upon its much faster switch on/off time, LED technology can be exploited in order to support the data networking (Daukantas, 2014). The usage of LED source in streetlamps has been reported achieving up to 500 MBps, i.e. 4 Gbps (Rani et al. 2012; Dutta et al. 2013, Sharma et al. 2014). In the above, the relevance of data networking for a "smart city" has already been pointed out.

The communication channel can be depicted in a very simplified way on the basis of the following 5 main elements: a) *Channel coding device* (data stream to light levels); b) *LED*; c) *Medium* (between LED and the Receiver); d) *Receiver*; e) *Channel coding device* (light levels to data stream).

A) CHANNEL CODING DEVICE (DATA STREAM TO LIGHT LEVELS)

This element adapts the info stream to the LED behavior. An info stream typically is a continuous flow of bits (0 and 1) coded with 2 voltage levels (for example 0 is coded with 0 volt and 1 is coded with 3 volt) that has to be adapted to flickering required for the LED.

The impulse to drive the LED are defined symbols and are obtained through a process called modulation. The starting point is a simple level conversion, according with two light level (L0 and L1) that have to be correlated to 0 and 1 bits. So if the *Info flux* is 1 Gbps the *Light flux* is 1 Gsps (Giga symbol per second). If the environment and the receiver support multi-level lights, the light levels available to transmit the info can be more than 2; for example 4. If 4 levels (L0, L1, L2, L3) are used while maintaining the same symbol rate, the info flux can be double. To achieve this symbol-to-level conversion the LED driver chip has to be more complex because it has to store 2 bit and to allocate the right impulse level for the LED. This modulation technique can be enhanced up to 256 levels.

According to signal theory, the numbers of symbols to be adopted in the modulation process is function of number of bits that every symbol has to carry. This can be expressed as:

$$\#S=2^{\#b}$$

where #S is number of symbols and #b is the number of bit to be carried for each symbol.

The modulator is flexible and can performs several MS (Modulation Schemes) according to the number of symbols adopted. Usually MS1 uses 2 symbols, MS2 uses 4 symbols and so on.

B) LED

In this paper, the term LED can refer to a single LED device or to a set of LED devices arrayed in a given pattern. Anyway, each LED can be described in terms of:

- frequency of emission (color);
- intensity of emission (discrete light levels described before);
- relative position within the LED pattern.

For instance, the pattern of LED, according with the utilization of the streetlamp, can be a 10 x 10 matrix or greater.

The LED emitter device is equipped with *ad hoc* mirrors and lens to optimize the light flux. Mirrors and lens are passive component that address and focus the emitted energy in the direction designed. They, as the antenna in radio wave communications, play a key role in defining the signal attenuation from the transmitter to the receiver (i.e. the link budget).

C) MEDIUM (BETWEEN LED AND THE RECEIVER)

The medium between LED and receiver is very important because it determines the throughput of the system; it is obviously the air (when dealing with streetlamps) and its main parameters are distance and weather conditions. The distance and the weather conditions constrain the choice of the modulation technique to be adopted. Gebhart et al. (2004) carried out test measurements in order to evaluate the FSO (Free Space Optic) in fog conditions.

It was found that fog can cause an attenuation of about 200 dB/km (attenuations up to 500 db/km have been reported). Taking into account the typical height of a street lamp, the above implies a fog-related attenuation of about 5 dB. On the basis of the foreseeable interval of attenuation, the *Channel coding device* has to adapt the numbers of levels to be used in the modulation scheme. If the *Medium between LED and the Receiver* produces a low attenuation (in the best weather conditions), the modulation scheme can use several light levels; on the contrary, if the attenuation is high (e.g. during fog phenomena) only 2 light levels can be used.

To achieve this smart modulation scheme it is necessary to predefine an attenuation measure tool. To such purpose, a *Dedicated signal* or a *Check attenuation pattern* are usually set up. A *Dedicated signal* can be provided by a dedicated LED of a color not used for info transmission or by a shared (on a time basis) LED of a color used to transmit. The *Check attenuation pattern* is a pattern not used for user info exchange. Typically, a Li-Fi application exploiting the streetlamps is a Point to Multipoint; accordingly, the smart application scheme has to be adopted for each link of each user.

D) RECEIVER

The receiver is the sensor that converts the optical flux into an electrical signal (as a webcam). The sensor element is provided by a photodiode; it is built as a LED but it works in the opposite mode. In this contest, it is worth noting that the receiver is a pattern of photodiodes that reconstruct the n-dimensional signal. Nowadays, low price web cams have a resolution of 16 Mpixels; the transformation from optical signal to electric impulse is simply a commodity.

E) CHANNEL CODING DEVICE (LIGHT LEVELS TO DATA STREAM)

This component performs the reverse function of the correspondent one in the transmission phase.

4 SENSING THE SMART CITY

As pointed out in the above, Li-Fi is able to provide a valid solution to the problem of the scarcity of available band, moving from radio-frequencies to the visible portion of the electromagnetic spectrum, thus relaxing a strong physical constraint to the data exchanges related to the life of a smart city. Accordingly, the network can support a higher number of users. However, another physical constraint has to be dealt with: the footprint of many different sensors. As far as the capture of data and the information generation is entrusted to automated sensors, the 3D space required by such sensors in a city cannot be neglected or given for granted, even if the new generations of the devices are steadily increasing their level of miniaturization (Borga, 2014).

It should be taken into account that the recent IPv6 protocol (based on 128 bits) allows to assign about 3.4×10^{38} addresses; therefore, the IoT (Internet of Things), where every object of the real world can be uniquely identified and the interaction M2M (Machine –to-Machine) is natively supported, is going to be an operational ecosystem. The plenty of possible IPv6 addresses translates into a density of about $6{,}6 \times 10^{23}$ objects potentially indentified per square meter of Earth surface; as a consequence, there is no more a ICT limit (inside any horizon of interest) to the amount of sensors (static as well as mobile) deployable in a urban area. Therefore, a proper planning and design of the sensors is mandatory.

Again, the infrastructure of the streetlamps can be of help, at least as the static sensors are concerned. It can be safely assumed that each streetlamp is *de facto* connected to a power grid of some sort or to a bank of solar cells, thus meeting the basic requirement of the power source needed by every static sensor. Moreover, each lamp has to be designed to bear dynamical stresses related to various natural or man-induced phenomena (temperature, wind shear, road traffic, etc.). The necessary mechanical structure shows in general many unused surfaces, where it is easy to implant the needed sensors (possibly, without expanding the global footprint.

As a result, it can be envisaged an enhanced streetlamp with several add-ons, e.g.:

- sensors: weather measures (temperature, humidity, pressure, ..), pollution measures (PM10, CO, ..), audio and video surveillance, localization monitoring (GPS);
- network devices: electricity connection, solar cells, batteries; Ethernet link (copper or fiber);
- access point devices: Wi-Fi; LTE base station (additional cellular operator coverage), Li-Fi.

Relying upon the available surface (also clustering the add-ons in suitable ways), the configuration of each streetlamp can be tailored in order to meet the local requirements. In the following, more information is provided about some add-ons.

4.1. SOLAR CELLS

The solar (photovoltaic) cells are designed to convert the energy of solar light into electricity, therefore they are useful where a power source is not available or reliable. The solar cells are quickly evolving. either in technology and in performance. In the eighties, about five different solutions were available, with a conversion efficiency of about 8 to 13%; currently, the efficiency is usually about 18% (as in the case of Panasonic HIT – Heterojunction), while very high performance solar cells can achieve an efficiency of more than 40%.

Thermophotovoltaic cells exploit heat differentials, instead of the direct light. The device has two layers. The first layer converts the sun light into thermal energy and emits the thermal energy based on black body emission frequency, i.e. according with its temperature, mainly in the infrared bands of the spectrum. This first layer has a very high conversion efficiency. The second layer is a traditional solar cell but optimized to work with a single frequency radiation, i.e. the one emitted by the first layer. This tuned solar cell has theoretically a conversion efficiency higher than traditional ones. Multijunction solar cells are solar cells composed of one layer over the others where each layer is optimized for a single optical band. A 5-junction solar cell can achieve an efficiency of up to 38.8% (NREL, 2014).

4.2. WEBCAMS

Webcams (i.e. videocameras sending live or still images over Internet protocols) can be used to capture information for many purposes, e.g. traffic monitoring, accident signaling and video surveillance. Their quality parameters can vary in a wide range: number of dimension (2D or 3D); view format (16:9 or 4:3); image resolution (from 640 x 480 to 1280 x 800 and over); frame recording (from 30 - 60 to over frame per seconds); minimum illumination (up to zero lux). Most of webcams currently have a color depth of 24 bits, i.e. 8 bits for each fundamental color of the RGB scheme (Red, Green, Blue).
If equipped with infrared LED (standalone or as backup of LED on streetlamps), webcams can capture information also during the night hours. When combined with LED lights, a webcam can be used (as a receiver) to communicate in Li-Fi technology. In order to achieve high speed transmissions, the color depth of the webcam is crucial, as well as the turn on/off time of the LED light.

4.3. GPS (GLOBAL POSITIONING SYSTEM)

The GPS system (as well as its analogous GLONASS and Galileo systems) provides positioning services, supporting the assessment of the geo-coordinates of a given point on the Earth surface. The telecom industry exploits GPS also for network synchronization at nanosecond level. It is worth noting that deploying the GPS on the streetlamps helps to minimize the interference among Wi-Fi hotspots and allows an easy tool to keep updated the database (the infrastructure components are tagged with their geo-coordinates that are steadily provided by the GPS; any change of such tags implies a modification of the infrastructure and vice-versa).
Another very important application is the development of the Ground-based Regional Augmentation System (GRAS) using GPS-RS (GPS Reference Stations) (Loiacono et al. 2009). GRAS is meant to increase the precision of GPS localization and to reduce the TTFF (Time To First Fix) of the users near a given streetlamp. The basic concept is that the GPS-RS deployed over the streetlamp assesses its position through the GPS satellite constellation and compares it with its nominal position, as detected at the installation phase (measure of position via topographic technique). This comparison produces the error measurement that can be uploaded to a database and be available to others GPS utilized by users in the area of the streetlamp. The final results are that the users reduce the TTFF and achieve a greater precise positioning measure.

4.4. SMARTPHONES

A mobile phone in itself is not a sensor; however, when augmented with the advanced functionalities that are implied by the term "smartphone", it constitutes a fundamental component of the system described in the above. Apart from managing the interface between the system and the human users, the smartphone carries sensors, interacts with the hotspots hosted by the streetlamps and therefore produces data that can be sent over the network and shared with other users (both humans and machines), e.g. the accelerometer sensor can be exploited to measure wind shear or vibration in the street caused by heavy vehicles or earthquakes.

Sensor	Current [mA]	Resolution
Accelerometer	0.3	0.0006 m/s^2
Gravity	12.4	0.0006 m/s^2
Linear acceleration	12.4	0.0006 m/s^2
Gyroscope	3.1	0.0003 rad/s
Light intensity	0.8	1 lx
Magnetic field	6.0	0.06 μT
Orientation	6.0	0.06 μT
Atmospheric pressure	1.0	1 mB
Proximity	0.8	8 cm
Temperature	0.3	0.01 °C
Relative humidity	0.3	0.04%

Tab. 1. List of sensors carried by a Samsung Galaxy S4 (Operative System Android 4.3)

Tab. 1 lists the sensors carried by a typical smartphone, together with the level of relevant electrical currents. Being the voltage given (it depends on the model of the smartphone), such currents are proportional to the energy demands and therefore provide the relative load of the sensors: it can be noted that the energy demands are quite low and therefore the sensors can easily be deployed in clustered or packed arrays.

4.5. LTE ENB (RADIO ACCESS POINT)

The network technology called eLTE (evolved Long Term Evolution) is the state of art of commercial mobile phone services. As other previous technologies (GSM, UMTS, ..) it is based on BTS (Base Transceiver Stations) that set up bidirectional links with mobile phones. In the eLTE terminology, the BTS are called eNB (enhanced Node B). The streetlamps can be equipped with eNB to increase the radio coverage, to reduce the average radio pollution and to increase the bit capacity.

5 CONCLUSION

Li-Fi shows very interesting features that can usefully exploited in order to support the networking and the sensing of a "smart city". Together with other technological developments (as those mentioned in the above), Li-Fi provides a consistent set of tools apt to increase the quality of life in a urban environment, mainly in terms of available information and of accessible services of interest of the citizens. The relevant financial investments appear to be of limited amount; in any case, some of the investments can have an actual return (in terms of added value of the provided services) and therefore public-private partnerships can be envisaged.

However, as already pointed out, paving the path towards the "smart city" implies also the mobilization of the human factors (from a local political leadership to a diffused entrepreneurship) as well as the improvement of the rules governing the system. The technology can play its role, but nothing more than this role.

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IMAGE SOURCES

Fig. 1: UNDESA (2012); Fig. 2: US DoE (2013).

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