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Leveraging technology evolution for better and sustainable cities

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Abstract. Everywhere we see municipalities setting up projects for Smart Cities. It has become a sort of a "mantra" word. But when we look at their plans we get different perspectives on what they call a "smart city". Sometimes they refer to smoother traffic, rational use of energy, sometimes to garbage recycling, sometimes to a healthier environment, … These are all "improvements" and obviously desirable ones.
However, what is it that characterizes a city to the point of being called Smart? In this paper I claim that it is awareness of the infrastructure and the capability to increase awareness of people living there.
In an ideal world we already have all the technologies we need to create awareness of designing our cities from scratch. This is what is being done in places like Songdu and Masdar. But in "our world" we already have cities and the challenge is to evolve them in an economically sustainable way in synch with their inhabitants expectations, needs and desires.
We can leverage technology evolution for this as well. And this is the focus of my talk. How can we make use of technologies like embedded electronics, screens, data harvesting and analyses (big data) and infrastructures like LTE with its native IP to evolve our cities into smarter places where people love to live.
In doing that I'll make reference to some particular examples, like the projects in Italy on the Smart Cities Cluster and in projects in the EIT ICT LABS framework.

Keywords: Smart City, Security, Emergency communications, Law enforcement

1 NAME YOUR PLEASURE, I CAN SELL

We are living in a world of technology abundance. It is difficult to run into a situation where you are stuck because there is no technology available to support you. True, there are some areas where simply the needed technology doesn't exist (yet) but by far we have the technology we need. Unfortunately, in many cases we cannot buy it! The cost is still too high, it is not affordable ... yet.

In fact, we have learnt that the technology price, particularly in the ICT area, is decreasing at a rapid pace so we can rest assured that in a few years that technology will become affordable.

Hence, let's forget for a moment the issue of cost and let's start to look at what we need when the goal is to have a "smart city" and what we have either on the shelves ready for use or in some research labs..

What does smart mean? Well, someone is smart if he or she is able to interact and react in an appropriate and effective way to his or her context, fulfilling her objectives.

Being "smart" then requires the capability to be aware of the context and since this context is reacting to one's behavior (this is surely the case when you interact with another person) to make sure that the context too is aware of what we are after (there can be of course a slate of added complexities like sometimes being smart may require to fool the context or be able to understand that the context is trying to fool you, but in the end all boils down to awareness).

Technologically speaking, awareness requires at least four activities:

- sensing
- processing
- understanding
- communicating (acting).

2 SENSING

The sensors' technology has made an amazing progress, as it can be confirmed by the number of sensors all around us. We probably have a gyroscope in the cell phone, accelerometers in the car, a light sensor on the TV set, a motion detector in the anti-intrusion system, a face detector in the digital camera and so on.

Our cities have sensors to measure traffic and pollution, for surveillance, for insects; our economic system has (physical and virtual) sensors to monitor distribution, capital flow, spending, goods appeal; the health care system uses sensors to detect upstart of epidemics, to check your breathing and pulse, the glucose level in your blood and so on.

Already today we can estimate that in the developed countries there is at least a hundred of sensors per person (your new car has at least 50 sensors...).

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The expectation is to have by the end of this decade a thousand of sensors for each person and that means a few trillions of sensors in the world.

Each of them will produce data, possibly several times a day, hence we will be flooded by PB on a daily basis (today traffic on the Internet is approaching the EB so a 1/1000 increment is not something to be concerned about).

What is important, though, is not the sheer amount of data, but that these data can be analyzed and can generate more data. In other words, data are becoming sensors themselves. I tend to call these "virtual sensing".

Evolution in sensors is progressing over three main directions:

- better and broader sensitivity. Sensors like the HP accelerometer can detect a variation of 1/1000 of the gravity force. That sensitivity allows the detection of minute vibrations to the point that one of these sensor glued to a wall at home can detect people walking, a faucet being opened, the washing machine having a loose gawking, and much more. It can detect the insurgence of a pathological condition (24 hours before being hit by a stroke a person changes his gait and that is detected by the sensor as a pattern change), and a structural problem in the floor... The mixing of bio and electronics broadens the parameters that can be sensed, from the ripeness of fruits to the presence of pollutants...
- lower power consumption. Electronics can be powered in μW and at this level it is possible to harvest such a power from the environment, through scavenging, be it vibration, light, radio waves, thermal or glucose (this latter is used by sensors planted in our body to get rid of battery). Having solved the powering problem it becomes possible to disseminate thousands of sensors in any ambient (and this is what fuels the proliferation of sensors, and in turns the ever decreasing price).
- embedding. More and more sensors are becoming an integral part of any object. The "packaging" of sensors exploits the reduced size and often the possibility to bend and adapt to any surface of the new generation of sensors. Printed electronics makes it possible to spray sensors directly on a surface, at a low cost. The progress in smart materials is leading to the use of materials that have intrinsic sensing capabilities, any surface will be able to detect a contact and the relative position to detect temperature and vibrations. More than that. Smart materials can remember and "learn" through interaction and communicate with the ambient and nearby objects.

3 PROCESSING

On the micro scale, processing has become cheap, both in terms of $ and in terms of energy. Hence it can be integrated in sensors for local analyses, reducing the number of bits that need to be sent, something that is still, and will remain, costly in terms of energy budget. On the macro scale processing delivers an enormous number crunching capabilities making it possible to perform sophisticated analyses, such as those required in image recognition, signal spectrum analyses, biologic digital signature recognition and so on. It has also become, thanks to the pervasive infrastructure, delocalized and parallelized. We are moving towards an "ambient processing" where a variety of computation units may cooperate, in a loose sense, to provide ambient awareness. Here we can also expect that the use of memristors, in the second part of this decade, will enhance the concept of global computational state applicable to an ambient and that will be a fundamental part of contextual awareness.

4 UNDERSTANDING

The progress in understanding has mostly derived from massive data analyses, statistical approaches and pattern-recognition techniques.

Understanding, in the context of a Smart Ambient, such as a Smart City, requires the assessment and concatenation of a variety of tiles to create the complete mosaic. It is not enough to understand that a car is slowing down or speeding up. One has to consider what the other cars are doing, what is going on at that particular place and time, who is driving and what his or her motivation might be and so on. It requires knowledge about the current status and previous experience. It also requires the capability to look ahead and correlate the various aspects in a single picture.

In the future, and in the context of Smart Cities, we can expect that understanding will be local, in the sense that many players will derive their own autonomous understanding based on the perceived context. In turns, their behavior will condition the evolution of the context and that will change the understanding of other players sharing (totally of partially) that context.

As the number of players multiplies and will become dense, we might expect the emergence of some forms of global understanding and behavior. It is not the result of a controlling or orchestrating actor but the continuous interplay of many actors, each one with its own agenda. This is what happens in the Nature's ecosystems where continuous, although independent, interactions can generate the perception of an "intelligent design". On the contrary, this is just the emerging intelligent behavior resulting from a loose interplay of many actors.

The challenge for an artificial environment, like a Smart City, is to have sufficient flexibility in the behavior of individual players that can result in continuous adaptation, thus leading to a coherent whole. Of course, we have this continuous adaptation in people, what we need, and will have, are continuous adaptations in objects, infrastructures and ambient.

5 COMMUNICATING (ACTING)

The leap from independent individual players to a coherent ecosystem is an essential aspect of future Smart Cities, although I have seldom seen this mentioned.

It is clear that within a complex environment, like a Smart City, there will be many players having different agendas, based on different technologies at various stages of evolution. It is impossible to freeze everything and have everyone marching at the same speed under the same orchestra conductor. This has to be taken into account to create an effective Smart City that can continually evolve and get smarter and smarter as time goes by.

This can be achieved through two fundamental communication fabrics: links and data.

Links make possible the access to data, not necessarily, as we would have said in the past "the interchange of information". The problem with the interchange of information is that there should be an a-priori agreement on what the information is and how to exchange it. This is simply unrealistic as the number of players, and data, keeps growing and changing. Cells in a body are apparently synchronized, but as a matter of fact they seldom communicate with one another (there are obviously exceptions). Each one reacts to local conditions and in reacting it changes them leading to ripples that affect other nearby cells and even some far away. There is no "a-priori" agreement on communications protocols nor on information to be exchanged.

Communications based on the paradigm of autonomous systems is probably the most effective one, given our present grasp of technologies.

This requires the availability of a local communication fabric, and wireless is clearly the way to go. Probably a variety of wireless overlapping infrastructures is required and will be de facto deployed. Each player will probably use one kind of the infrastructure and some players will be able to use several infrastructures acting as a relay to those that can only access one.

This does not mean that we no longer need high capacity long-range infrastructures. Not at all. It just emphasizes the growth of local nets (halo nets) and the local capability of internet communications.

Data represent the other facet of communications. Data are shared and players process the existing data and create new data. Here again we would have required an "a-priori" definition of semantic categories, an agreement on the syntax so that data can be exchanged and understood.

However, this is not what happens in Nature. Complex systems are flooded with data and learn by themselves to understand and make use of them.

This, to a certain extent, is what will be required in a Smart City environment. The key to provide useful data is an open data framework and the encapsulation of data in micro access devices (API-Application Programming Interfaces). There is a need to move up in the hierarchy of API, transforming them into snippets that provide both the access to data and the key to their manipulation.

Imagine the situation today in accessing music. You get a song, but in order to "play it" you need to have the right codec and hence know how it has been coded. It is not a surprise if sometimes you get an error once you try to listen to a new "downloaded" song. A different approach is that when asking for the song; the song is delivered in a package that contains the player. What you get is the music, not the data.

This approach has the interesting property that you cannot "steal" the data since that data is never really available, only its effects are available. This decoupling may be very important in a Smart City context where data will be owned by different parties and will be subject to owners constraints.

One last remark on communication. The networks we have been designing for decades were based on the (correct) assumption of a certain traffic distribution, more specifically the average communications would last 3' and every person would communicate 4-5 times a day.

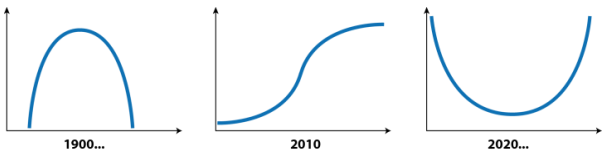

Figure 1. Traffic distribution graphs.

Hence the traffic distribution was like the one shown in the first graph with the peak of the gaussian corresponding to 3' four times a day (the y indicates the number of transactions, the x the number of bits carried by those particular transactions). The advent of Internet and multimedia (YouTube, Netflics...) has changed the actual traffic pattern with a tremendous increase in the bulky transactions made by a multitude of people. Hence the S curve. In the future, the trillions of sensors will be generating a multitude of transactions, each, on the average, consisting of just few bytes. This along with the continuous fruition of multimedia, leads to the inversion of the gaussian. It is obvious that the future network architectures will have to take this into account.

In Nature, we have plenty of similar situations. Cells in an organism are continually generating tiny communication packets (ejection and absorption through various means/protocols of molecules) and these have first a local effect and then they aggregate and bring information to distant regions through the big pipes (veins and arteries).

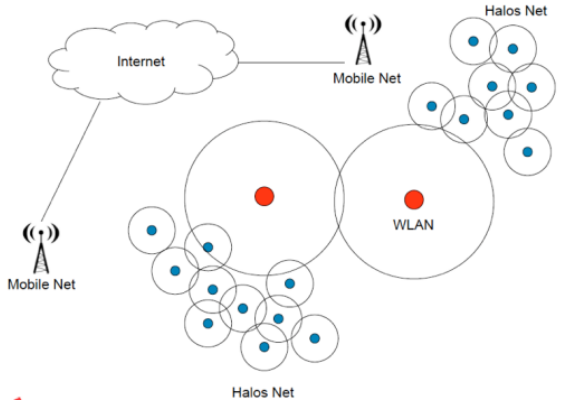

Figure 2.

Increased communications needs are managed locally and seldom the increased needs are affecting the main communications infrastructure (and when this happen, there might be nasty effects, like a shock and complete shut down...).

Communications architectures based on halo nets may represent a technological implementation of the Nature way of managing autonomous systems.

Notice that these halo nets can be created by the objects themselves, each halo, as an example, may be created by a vehicle and as it moves in the urban environment, it overlaps with other vehicles halos, thus ensuring a flow of communications, sharing the data it has associated to its halo (remember that data and communications tend to be two sides of the same coin). Interestingly, this approach creates more communications capability where there is more need for the communications capability, that is the opposite of what happens with the todays architecture where capacity is designed up-front and the unexpected overload impairs communications.

Communications for a long time has been based on the assumption that its "meaning" is derived by the people involved in it. It is up to the brains at the edges of the network to make sense of what is being communicated. Hence, there has been a clear separation between connectivity and meaning, the latter being independent of the former.

Over the years, mostly in the beginning of the 80ies, the network has started to provide some smartness to communications to better manage resources and to provide services to the "brains". The end points of the networks, the phones, have remained completely passive and disjointed from one another.

The advent of the Internet of Things has been seen as just another way to connect "dumb" entities to the network and indeed most of these things are "dumb" but their aggregation may not need to be. And in the context of Smart Cities, the networks will connect the contexts, rather than the end points, and these contexts will become smarter and smarter. Part of them will have their connectivity fabric and will be able to connect through that to the variety of components in their context and to a plurality of networks at "their" edges.

Moreover, meanings and connectivity within a context are strongly related, it might actually be impossible to separate the two of them, as it is the case in our brain where you cannot decouple axons/dendrites from neurons. Meaning is an emergent property of a network formed by entities.

What we are going to see, from the connection paradigm view point, is a 180' change: if in the past we (network operators) have been considering the network as the core and what is being connected as the edge, in the future contexts will be the core of connectivity, the fabric upon which services are delivered, and they will see "our" network as their edge.

6 Bits and Atoms

What awareness does is to transform a reality made of atoms into a mirror representation made of bits. This is not different to what happens with "our" awareness as human beings. Our brain is getting the atoms of the world by having them transformed into "bits" by our senses. This representation is contextualized in the brain by our memories and interpreted, modeled. It is on this model that we reason and eventually take decisions that are transformed into actions affecting the atoms of the external world.

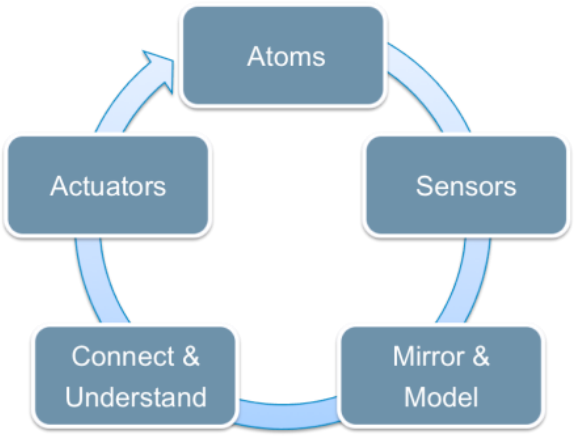

Figure 3.

Sensors capture the "characteristics of atoms" and convert them into bits. In turns, these bits can be used to create a mirror representation of the world that can be used as a model of the world itself.

This allows the analyses of the model to understand specific events and to grasp the emergent properties of the whole environment deriving from the independent behavior of its constituents.

The operation of "connect and understand", as already remarked, should not be seen as the need for an orchestra player that has a god-view of the world and dictates what is going on. Rather, the scheme depicted applies to each single player, it is each individual player, that, in different ways and with different capabilities, tries to extract its own vision of the world to decide how to act on its context.

Clearly, there will be a broad variety of players, and a broad diversity of the context. Those having a broader

context will access more comprehensive data and will be able to construct more encompassing models and hence get a broader (but less specific) understanding of what is going on and therefore take actions that are likely to affect a wider context.

What is important is that acting at the level of a model is cheaper than acting on the atoms.

Hence we are going to see a continuous evolution of services on the web: the associated transaction cost is very low and it lowers (destroys) the entrance barriers.

This is where we are going to see plenty of SMEs playing the game. This is where a single person, a "smart" student can develop his or her own service and offer it to the whole township.

In order to make this a reality, we need to open the "model", the bit/data space and let any player create services.

Notice that what is shown here as a single conceptual loop is actually composed of many loops, since we are going to see many sets of sensors sensing the atoms and transforming them into data. Thus we are going to have many focused representations mirroring specific aspects of a city (transport, health care, garbage collection and recycling, energy use, pollution....) and it is important to open all of them so that they can be connected to create services.

As well as a multitude of "sensing sets" we are going to have a multitude of interactions with atoms, through a multitude of actuators and services, each one in principle offered by a different SME.

This together creates the ecosystem.

7 A SMART CITY

I have set the basic building blocks, awareness and ecosystem, making up what I would call a Smart City. But who is going to judge if that is really "smart"? Me, you and them. Now, this is a problem because each one has his or her own idea of what "smart" means.

Often it is a matter of perception and hence it is subjective. The first characteristic of a smart city is its capability to adapt to me, you and them.

When you drive and look for directions, you are likely to be overwhelmed by signals pointing to many places, most of them outside your present interest. Wouldn't it be smart if I can see just one signal pointing me the way? We have the required technologies (although they are mostly in research labs but we have agreed to disregard this since we are talking about the future).

A signal on the road can be aware that I am in its vicinity, that I need to go in a certain place and therefore can display the information that matters to me. As you are driving in your car, just few meters behind and looking for a different place, the signal should also pay attention to you, if it has to appear smart to both of us. Well the signal is not actually showing the direction, it is signaling the direction to my (and your) car windshield and the information is displayed there, in such a way that it looks like it is being displayed on the signal. In this way each of us perceives the signal as providing customized information.

This example shows another crucial element for a smart city: personalization of interactions. This leads to a simpler interaction and of course implies the possibility to recognize which is which (or who is who). A signal does not need to recognize all passers by, it is enough if it declares itself to the environment as a signal providing a certain set of information. It will be up to the personal assistant associated to each person to turn that interaction into a meaningful one from our point of view.

This is another crucial aspect in the tomorrow's smart spaces: each component shall be able to declare its characteristics and functionality and leave its appropriate exploitation to some sort of agent associated to the user. It is the user that can decide what matters and how it matters.

This approach simplifies the issues like the management of privacy, since most personal information needed to customize the experience is owned and not disclosed to the ambient, and let the individual to decide the level of "smartness" he or she desires and possibly he or she is willing to pay for.

This assistant will interact with several sources of data and services and will sometimes adapt the data to the person, sometimes it will invoke/make use of specific services to obtain the required correlation.

A smart city, obviously, is not just smart from the point of view of one/all of its inhabitants and passers by. It is also smart from the city/community point of view. Hence, the same type of questions that one of its dwellers can ask from time to time are being asked, continuously, by the city itself (and by its neighborough, its buildings, its transportation systems, its infrastructures).

Questions like is everything ok? can I save energy? ... are questions that can be asked at different levels eliciting different answers and different actions. What can make sense at a certain level, like local optimization of the traffic flow, may be a suboptimal solution at a more global level.

What I see in the future is a constellation of objects with various degrees of "smartness", each one mostly reacting on the bases of its own context, and a higher level of aggregations, also possessing various degrees of smartness similarly reacting on the basis of their context. A smart city, in this view is nothing but a higher order aggregation that reacts to its context. Notice that at all levels (but the object one) the context comprises both the internal one - created by the aggregation of the contexts - and the external one.

Therefore, a smart city will have as the context its various components AND the surrounding territory.

One can easily think of modeling all of this as autonomous agents interacting with one another.

This approach has the advantage of being compatible with a variety of entities (both physical and

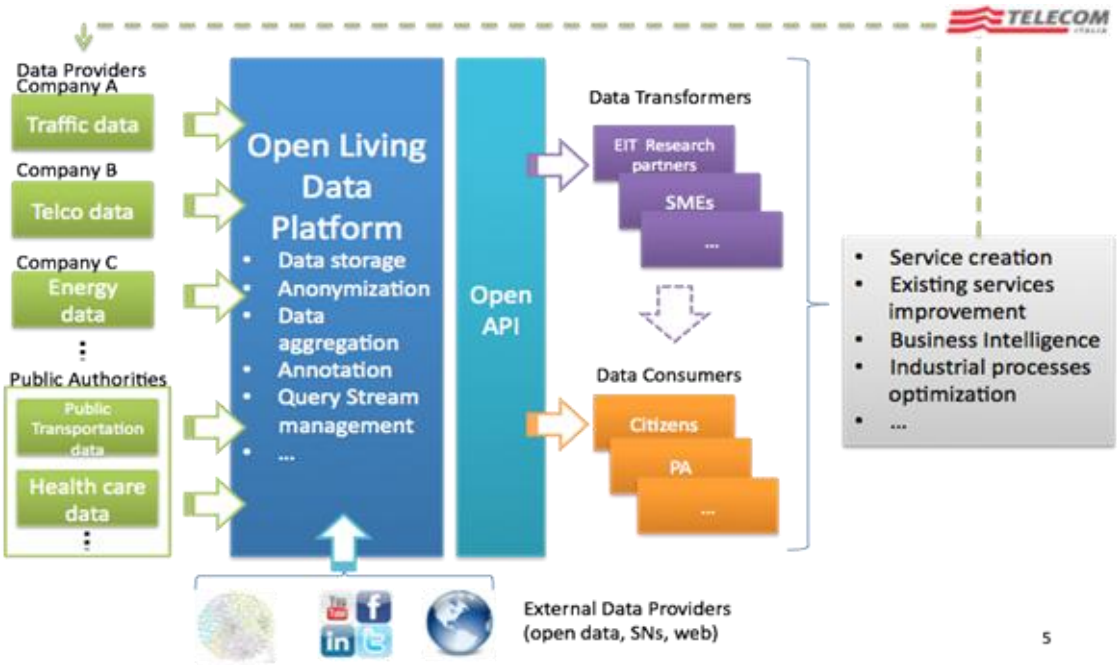

Figure 4.

logical/aggregations) each one with its own level of smartness.

A single citizen can decide what kind of smartness he need/can afford for the objects he is buying (how smart do I want my washing machine to be?) and the Major can decide how smart he wants the aggregation he controls to be and of course how much he is prepared to invest on that.

This solves the question often voiced: should a smart city be composed of smart entities or should it become smart in spite of the dull entities within its boundary?

It is actually neither. A smart city is as smart as it can be and part of being smart means getting smarter as it gets possible to get smarter because some of its components are getting better. It works also the other way round. A city that leverages on its aggregation provides each of its components with a smarter context, thus stimulating investment to take advantage of it, and therefore promotes increased smartness in its components.

It is important to get out of the atrophy resulting from the chicken and egg situation where one constituency doesn't bother to improve itself since the others wouldn't take notice and symmetrically the other doesn't see a point in becoming better since it still has to deal with a non-responsive environment.

I mentioned in the beginning that we have the technologies for creating awareness, here I say that we also have the technologies to sustain this kind of evolution based on autonomous systems. The complexity of the overall system of systems will lead to emergent behavior of the whole that need not to be paid up front.

Again, as I already said, I feel that a crucial enabler is an open data environment, and this is what the Province of Trento, with its partners, is building.

8 BECOMING SMARTER

Let's face it. Our cities are already smarter than they were fifty years ago. We have better infrastructures, although we might not realize it as we are stuck in a traffic jam or waiting long minutes for a bus under a rain-spell.

Today, our cities manage a traffic load that is many folds the one they did years ago, get cleaned in spite of the increased garbage production, serve an ever increasing hunger for energy and so on. They are surely smarter but they can be even better.

So the point is how can an administration guide the city evolution towards getting better and better steering the various players towards a global improvement that capitalizes and multiplies each single tiny improvement?

At the Italian government level, in September 2012 the Ministry of Innovation launched a bid for a Smart City Cluster of enterprises and universities that will tackle various aspects of smart cities infrastructures and services and will experiment in the field in many Italian cities in cooperation with local administrations.

The under deployment LTE infrastructure, operations in several Italian cities from December 2012 (although some trials have been active for over a year now), would create an ideal connectivity fabric for the Internet of Things since LTE supports the native IP and in turns a simple chip is sufficient for connecting to it (the target is a few $ per connection point).

The Province of Trento has set up an open data framework, with the help of the University of Trento

and TrentoRise, a promoter of innovations through selective funding of private initiatives.

This open data framework provides a legal background and guidelines to make data accessible to third parties in a controlled way. As a kick-start the Province has opened up a first part of its 120 data bases, created in the past as a silos dedicated to specific applications. More will be opened in the coming months.

Within this framework the Province has found interested partners, like Telecom Italia, Autostrade Trentine, Poste Italiane, that are at the same time willing to share part of the data they own and create a framework of service components that can be used by any third party to create services based on those data correlation.

As I mentioned over and over again in this paper, a city gets smarter if it can capitalize on the smartness of its components without requiring them to be "smart".

A research lab of Telecom Italia based in Trento, SKIL, focussing on semantics, is at work to create correlations across raw data and the ensured data can be exposed even after the correlations are made with no breach of privacy.

A business framework has also been developed to ensure that the value accrued through the use of data, in whatever form, can be monetized.

As the work on the data infrastructure is progressing, special projects have started, like the Smart Campus carried out at the University of Trento. Another one is involving students who have received smart phones and that can opt in to disclose their data (when and what being decided by each of them). This allows the accrual of other data that feed the data base of SKIL. Another project accrues data provided by security cameras in an art museum to study the behavior of visitors (whose identity remains hidden), another is testing safety measures and traffic pattern on roads ...

Each of these projects has an intrinsic value and serveş the purpose of those who funded it. However, by being inserted in the open data framework, they provide the bises for third parties to leverage them and create further value. Altogether they are part of the smart city ecosystem. As each one gets a bit smarter, third parties will find ways to capitalize on this and will increase the overall smartness.

The work is far from being completed, actually it will never be completed since nothing will ever be so smart that it couldn't get any smarter!

Besides, the ideas reported in this paper are under scrutiny through trials to be carried out in the coming two years, also in the context of the ICT LABS activities in the areas of Smart Spaces and Digital Cities of the Future. An additional contribution will come from other areas addressed by the ICT LABS, like Privacy Security and Trust, Computing in the Cloud (that is also addressing Big Data aspects), Intelligent Mobility and Transportation Systems and Smart Energy Systems.

9 SUMMARIZING

Our cities will become smarter, because this is a general trend, even if we are not taking any action. However, by taking an action, we can accelerate the evolution and create business opportunities for SMEs. The parallel with the apps ecosystem is obvious. There the ecosystem seed is the opening of OS resources and a platform managing exposure, delivery and payment. Here, the ecosystem seed is the creation and sharing of the context, that is open data plus a platform created by the city administrations providing the regulatory framework.

From the technology point of view, the enabler is the theory of complex and autonomous systems that explains behavior emerging from interactions.

From our citizens/inhabitants point of view, the "Smartness" is related to the perception of an environment that is aware of us, as a whole and in many of its components: infrastructures, transport, logistics, health care, services, resources management...

Smart Cities are Cities, and they belong, first of all, to their citizens. It is crucial to involve citizens at all stages of the transformation. They have to feel part of it and in charge of it. New technologies can now provide a youngster the possibility of creating services, tiny ones perhaps, but in a huge quantity, so large in fact that makes it possible to observe what people like and what they don't and finally tune the evolution.

In Trento, one of the best things that we are doing is involving the college and university students in the design of services for their city.

At the EIT ICT LABS we are funding a number of activities for millions of euros that aim at creating such ecosystems and we should be able to see the results within the next two years. And we are funding a Master School focusing on the various aspects that are needed for creating and managing a smart city, thus involving students and giving them the tools to become entrepreneurs in this area.

ACKNOWLEDGMENT

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