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Editorial

Networking and communications for smart cities special issue editorial

Our society is facing an unprecedented massive urbanization. At the time of writing, 54% of the world's population lives in urban areas (with an 82% peak in North America), opposed to only 30% in 1950. Reports [1] predict that 66% of the world's population will be urban by 2050, i.e. a sheer increase of 2.5 billion urban citizens, owing to the absolute population growth. The obvious (but not nearly trivial!) emerging challenge is how to successfully accomplish a sustainable urbanization at such level and scale.

Information and Communication Technologies (ICT) are expected to play a crucial role in the sustainable development of new urban environments. The term Smart Cities has been coined to identify technology-intensive cities which provide the ability to gather, analyze, and distribute information so as to transform services offered to the citizens, improve operational efficiency, and entail better decisions at the municipal level. For instance, smart buildings exploit a multiplicity of sensors and control systems to measure their environment and control it in real time, so as to improve reliability and security, to reduce maintenance costs, improve energy efficiency, and so on. Smart metering solutions allow a utility company to match production to demand, dynamically. Smart utility solutions influence both production and demand through smart grid technology.

This special issue not only builds on the evidence that networking and communication technologies will play a crucial and pervasive role in Smart Cities. It is also, and mostly, motivated by the desire to contribute to answer the following foundational question: what are the "unique" context characteristics, application needs and traffic/user patterns in today's and tomorrow's Smart City environments which require redesigning networking, communication technologies and systems, and call for a rethinking of their relevant modeling and dimensioning methodologies?

Indeed, networks designed for Smart Cities, or adapted to fit the urban context requirements, have some unique characteristics or attributes which distinguish them from traditional "general purpose" networking and communication systems; key features include (but are not restricted to):

very large densities: Smart Cities may comprise tens of thousands of smart devices, generating data either sporadically or periodically;
unusual traffic patterns: synchronization or cascading issues among smart devices may yield highly correlated and/or bursty traffic patterns, very different with respect to the usual human-generated ones, for which most of our community's planning and dimensioning tools and methodologies are based;
unstructured topology: unlike the Internet which is mostly structured in a hierarchical way, a Smart City is meshed by nature, and use mostly wireless connections. The deployment of a single high-throughput backbone looks therefore very unlikely;
heterogeneity: a large number of widely different technologies coexist, each operating at a different tradeoff point between communication ranges, energy consumption and throughput;
security: confidentiality, integrity, authentication and privacy of data are a sine qua non requirement for Smart City applications. It should not be possible to turn any of these conditions off;
coexistence: several technologies and independent radio infrastructures are deployed in the same radio space, often on unlicensed bands; being able to elegantly deal with interference is therefore essential.

1. Open challenges and opportunities

A number of fundamental challenges are specific to Smart Cities; addressing these challenges is the key to their unhindered development.

1.1. Lack of standardized solution

Wireless Multi-hop Networks have attracted significant academic interest in the last decade. This research has sparked the development and commercialization of a large number of proprietary solutions. This has resulted in technology fragmentation, an obstacle for the Smart City market in which complex heterogeneous systems of sensors and actuators need to form a homogeneous communicating entity. Only the development and agreement on a set of standardized solutions allows the creation of "umbrella" networks covering an entire urban area, and through which devices owned by different public and private entities communicate. In the future, a small number of Telecom Operators will administer, run and monetize these networks, in a way very similar to today's cellular networks.

Major standardization bodies are well-aware of the lack of standardized solutions, and are well underway in answering it. The IEEE802.15.4 standard has been at the forefront for providing a physical layer which offers a healthy trade-off between power consumption, communication range and data rate. Recently, a number of amendments were published for targeting Smart City application. The IEEE802.15.4g amendment defines a new physical layer which allows ranges and data rates compatible with neighborhoodwide mesh networks. The IEEE802.15.4e amendment (which can be used in conjunction with IEEE802.15.4g-compliant

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radios) modifies the way devices access the wireless medium, and its Timeslotted Channel Hopping mode offers both ultra high reliability and low-power. Beyond these low layers, the Internet Engineering Task Force (IETF) has been adapting Internet protocols to "constrained" networks of low-power devices. IETF standardization efforts most applicable to the Smart City space are 6LoWPAN, an adaptation layer enabling even the smallest device to be IPv6-compliant and appear as regular hosts on the Internet, and RPL, a routing protocol allowing the creation of multi-hop meshes. More recently, the IETF 6TiSCH working group was created to define how to build "umbrella networks" taking advantage of the unprecedented performance of IEEE802.15.4e TSCH.

1.2. Systematic cooperation

Networks operating in a Smart City cannot (anymore) be considered as a collection of independent infrastructures. In particular, we should address the following challenges:

interference: the different networks must cooperate to share the unlicensed band. Techniques issued from cognitive networks should also be adapted for this kind of applications. The impact of e.g. Bluetooth, Wi-Fi and micro-waves have already been studied [7];
vertical soft handover: a growing number of devices have multi-radio capabilities. They should carefully select the most accurate interface to use, trading-off throughput and energy-efficiency [9];
crowd sensing: exploits the multiplicity of mobile devices and objects to obtain a large collection of measurements. Because a large amount of data has to be collected, devices must cooperate to aggregate those measurements [10].

1.3. Re-usability and interconnection

In the next decade, we will see a move from independent networks operating as interconnected islands, to the federation into a shared infrastructure. Rather than having one deployment per application, wireless access will become a service, available on a range of technologies operating on a combination of licensed and unlicensed frequency bands. To speed up this trend, this infrastructure needs to offer:

security: secure and reliable communications is a must, with privacy becoming a key requirement [2];
flow isolation: with the same infrastructure used by different clients and applications, it is important to be able to guarantee (and charge for) a certain level of Quality of Service (QoS). A surge in water monitoring data due to heavy rains must not impact the regular flow of parking monitoring data [5].

1.4. M2M interactions

Smart Cities are filled with Machine-To-Machine (M2 M) interactions, with very specific networking characteristics:

local traffic pattern: while some sensor data might be sent to a remote data center, consumption within the network will become prevalent. Fleets of networked vehicles will exchange information about their immediate surroundings, without going through a remote data repository. In these cases, decentralized operation is important. Traffic patterns can reveal insights for better management of shared network resources, eventually leading to better QoS for all types of devices [11];
short messages: while protocols on the traditional Internet are designed for long data packets, the smart sensing and actuating devices automating a Smart City communicate using very short messages. This impacts congestion detection and avoidance [12,3], and encourages in-band aggregation [4,6].

1.5. Application opportunities

The future is today when it comes to Smart Cities. Numerous innovators and start-up companies develop commercially relevant successful products, and the Smart City is filled with success stories. The most well-known applications revolve around parking monitoring. By installing sensors able to detect the presence of a vehicle on each parking spot, Streetline[1] reduces the time looking for parking by 43%. LoadSensing, a WorldSensing company[2] equips large urban infrastructure with myriads of small sensors to monitor the health of the structure, leading to a safer urban environment. Smart Cities are only at their infancy, and the long road ahead is bright. Exciting new research announces the emergence of city-wide integrated solutions. One example is the "Internet of Water" lead by Branko Kerkez at the University of Michigan, in which the entire network of clean water and sewers is monitored in real time to ensure optimal water quality, and reduce the risk of flooding in exposed neighborhoods [8].

2. This special issue

This special issue received 24 submissions covering many heterogeneous networking and communication topics in the Smart City domain. Via a thorough review process, a total of six papers have ultimately been selected for inclusions. Of those, five are mostly focusing on research contributions, whereas one paper has a more tutorialistic nature. Since the selection of the papers (once verified they were in the scope of the special issue) has been exclusively driven by the quality of the submissions and by the relevant reviewers' comments, we cannot of course claim that the collection of papers included in the special issue exhaustively covers all the key challenges and issues emerging in the Smart City domain. That being said, we are happy to report that the special issue features a rich and well assembled mix of contributions, covering a broad range of technologies and solutions.

The article "Interoperability Issues on Heterogeneous Wireless Communication for Smart Cities" presents an architecture to integrate heterogeneous wireless networks. Edson Avelar et al. envision a wide integration of Vehicular, Mesh and Sensor Networks in a global urban network, pushing data to the cloud. They propose to support quality of service through a Policy-Based Management and a Media Independent Handover approach. The authors provide experimental results about the integration of these different technologies, with a particular focus on sensor and mesh networks.

In the article "PARP-S: A Piggybacking-based ARP for IEEE 802.11s-based Smart Grid AMI Networks", the 802.11s standard is adapted to handle the Address Resolution Protocol (ARP) broadcast storm problem in Smart Grid Advanced Metering Infrastructure (AMI) applications. MAC address resolution is done during routing tree maintenance. This means that broadcasting ARP requests by the smart meters to learn the MAC address of the data collector is completely eliminated. The performance and overhead of the proposed mechanism is evaluated using the ns-3 simulator.

[1] http://www.streetline.com/
[2] http://www.worldsensing.com/

The detailed evaluations show that, compared to the original ARP broadcast operations, the proposed approach decreases the end-to-end delay without negatively impacting the packet delivery ratio and throughput.

Privacy is a main concern in Smart Cities: in smart grids, the system should be able to switch off some appliances to reduce their consumption so that it matches energy generation. However, this knowledge may have a negative impact on the privacy. To anonymize the collect, Cristina Rottondi et al. propose to use the Shamir Secret Sharing scheme to divide the requests and collect them through an anonymous routing protocol in their article ''Privacy-Friendly Load Scheduling of Deferrable and Interruptible Domestic Appliances in Smart Grids''. In particular, user identity and appliance consumption remain private and are not exposed publicly. The authors formally prove the security of their protocol, guaranteeing privacy.

Vehicular Ad-Hoc Networks (VANETs) will play a critical role in Smart Cities. With recent improvements in multimedia over VANETs, vehicles can cooperate with one another to transmit live flows of traffic accidents or disasters and provide drivers, passengers, and rescue teams with a rich visual information about a monitored area. In ''A Distributed Beaconless Routing Protocol for Real-time Video Dissemination in Multimedia VANETs'', Mario De Felice et al. introduce an application framework and a routing protocol that enhances the dissemination of live video flows on multimedia highway VANETs. They use a backbone-based approach to create and maintain persistent and high-quality routes during the video delivery in opportunistic Vehicle to Vehicle (V2V) scenarios. Performance evaluation results confirm the performance improvement of the proposed approach compared to existing work.

The survey article ''IEEE 802.11ah: an Enabling Networking Technology for Smart Cities'' describes the emerging standard for low power, decentralized Wi-Fi networks. Since this technology aims at providing connectivity to thousands of devices through a single access point, it may play a key role in enabling Smart Cities. Evgeny Khorov et al. describe the MAC enhancements to support a large number of power-limited devices. A large number of stations may transmit short packets only infrequently in Smart Cities. Thus, the standard proposes to spread the transmissions over a long period of time to reduce contention. In parallel, some relay nodes may be elected to forward the packets of a group of stations to extend the AP coverage area.

The article ''Orthogonal Circular Polarized Transmission for Interference Control in Femto-Macro Networks'' by Ponnu Jacob et al. presents a theoretical framework exploiting cross-polarized data transmission as a potential approach to improve the spectral efficiency of cellular systems, while at the same time allowing co-channel allocation. In the proposed approach, femtocell networks use right-hand circular polarization; macrocell networks use left-hand circular polarization. This allows simultaneous transmissions in the same frequency band. The polarizations being orthogonal to one another due to their sense of rotation ensures isolation between the networks and hence enables efficient frequency reuse. This promotes interference-free independent operation with better coverage and higher throughput. Even with minor imperfect calibrations, the framework increases the system capacity of femto-macro networks and allows efficient frequency reuse compared to conventional methods. The article also discusses how to implement the framework.

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References

[1] United Nations, Department of Economic and Social Affairs, Population Division (2014), World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).
[2] E. Ancillotti, R. Bruno, M. Conti, The role of communication systems in smart grids: architectures, technical solutions and research challenges, Comput. Commun. 36 (17–18) (2013) 1665–1697.
[3] S. Brahma, M. Chatterjee, K. Kwiat, P.K. Varshney, Traffic management in wireless sensor networks: decoupling congestion control and fairness, Comput. Commun. 35 (6) (2012) 670–681.
[4] P. Costa, A. Donnelly, A. Rowstron, G. O'Shea, Camdoop: exploiting in-network aggregation for big data applications, in: USENIX Conference on Networked Systems Design and Implementation, 2012.
[5] F. Cuomo, C. Martello, A. Baiocchi, F. Capriotti, Radio resource sharing for ad-hoc networking with UWB, IEEE J. Sel. Areas Commun. 20 (9) (2002) 1722–1732.
[6] E. Fasolo, M. Rossi, J. Widmer, M. Zorzi, In-network aggregation techniques for wireless sensor networks: a survey, IEEE Wireless Commun. 14 (2) (2007) 70–87.
[7] F. Hermans, O. Rensfelt, T. Voigt, E. Ngai, L.-A. Nordén, P. Gunningberg, Sonic: classifying interference in 802.15.4 sensor networks, in: IEEE/ACM International Conference on Information Processing in Sensor Networks (IPSN), 2013, pp. 55–66.
[8] D. Hill, B. Kerkez, A. Rasekh, A. Ostfeld, B. Minsker, K. Banks, Sensing and cyberinfrastructure for smarter water management: the promise and challenge of ubiquity, J. Water Resources Planning Manage. 140 (7) (2014).
[9] T. Jin, G. Noubir, B. Sheng, WiZi-Cloud: application – transparent dual ZigBee-WiFi radios for low power internet access, in: International Conference on Computer Communications (INFOCOM), 2011.
[10] J. Sahoo, S. Cherkaoui, A. Hafid, Optimal selection of aggregation locations for participatory sensing by mobile cyber – physical systems, Comput. Commun. (2014) (in press).
[11] M.Z. Shafiq, L. Ji, A.X. Liu, J. Pang, J. Wang, A first look at cellular machine-to-machine traffic: large scale measurement and characterization, in: International Conference on Measurement and Modeling of Computer Systems, ACM SIG – METRICS/PERFORMANCE, 2012, pp. 65–76.
[12] C.-Y. Wan, S.B. Eisenman, A.T. Campbell, Energy-efficient congestion detection and avoidance in sensor networks, ACM Trans. Sensor Networks 7 (4) (2011) 32:1–32:31.

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