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Interoperability issues on heterogeneous wireless communication for smart cities

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ABSTRACT

Smart cities have become a reality around the world. They rely on wireless communication technologies, and they have provided many benefits to society, such as monitoring road traffic in real-time, giving continuous healthcare assistance to residents and managing the environment. This article revisits key interoperability questions in heterogeneous wireless networks for smart cities, and outlines a simple, modular architecture to deal with these complex issues. The architecture is composed by sensing, access network, Internet/cloud and application layers. Different features provided by the architecture, such as interoperability among technologies, low cost, reliability and security, have been evaluated through experiments and simulations under different scenarios. The QoS support and the seamless connectivity between pairs of heterogeneous technologies are proposed through a policy-based management (PBM) framework and MIH (Media Independent Handover). Moreover, an 802.11 mesh backbone composed of different types of mesh routers has been deployed for interconnecting the sensors and actuators to the Internet. Key results from experiments in the backbone are examined. They compare: (i) the performance of a single-path routing protocol (OLSR) with a multipath one (MP-OLSR); (ii) the monitoring delays from the proposed low cost sunspot/mesh and arduino/mesh gateways; and (iii) the authentication mechanisms employed. Significant results from simulations allow the analysis of the reliability on vehicular/mesh networks under jamming attacks by applying the OLSR and MP-OLSR routing protocols. Finally, this article provides an overview of open research questions.

1. Introduction

In the last decade, there has been a growing demand for more attractive and efficient cities, in an attempt to reduce the effects of urbanization. Researchers believe that following the pattern of social change of the 1990s in some countries, new policies for sustainable urban planning are required as a result of the huge migration of people from rural areas to only a few large cities [1,2]. The high concentration of people raised different challenges for the government, such as uncontrolled growth, traffic congestion, crime, waste resource management and others. Furthermore, owing to globalization, cities started to compete with each other to attract the best professionals, by providing them attractive environments where they could live [2]. These challenges have led governments to adopt technologically-based approaches and handle the negative effects of urbanization via broadband interconnected cities, known as *Smart Cities*.

Governments around the world, including the Japanese, Germany and Brazilian ones, have made financial investments and efforts to apply Information and Communication Technologies (ICTs) for solving the issues produced by urbanization [3,4]. Wireless communication, embedded systems and wireless sensors are examples of ICTs that can benefit different dimensions of societies. ICTs provide integration among services in cities, collect real-time data, analyze them and lead better decisions. Those technologies have been considered by academic and industrial projects in many contexts, such as healthcare, intelligent transportation and energy savings, supporting the inclusion and assisted living; exploiting vehicle-to-vehicle and vehicle-to-infrastructure wireless communication to alleviate jam in the cities; and assisting the efficient management of power distribution grids, respectively [5,6].

However, the use of ICTs today is based on commercial solutions making **expensive** and **complex** the integration of devices, services and technologies. Big companies have promoted and sponsored the development of smart cities [7]. Hence, they encourage people to use their products, as software and hardware, that often

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cannot *interoperate* with devices created by other companies. Analogously, there is a significant amount of testbeds handling specific aspects of smart cities via off-the-shelf devices [8,9]. An example is the use of different sensor motes that, in general, are low cost but follow specific standards for physical and link layers, without defining how upper layers must work. This makes interoperability difficult even among devices from the same manufacturer, compromising network scalability.

As a result of government initiatives, several smart cities projects have emerged, such as SmartSantander [10], SOFIA [11], CitySense [12], Motescope [13], Friedrichshafen T-City [14] and others. However, most of these projects follow the traditional approach of employing expensive devices and proprietary software. There is a lack of work on smart cities that focuses on simple and low cost infrastructures. In this context, this study offers a low cost solution based on commodity hardware and open source software.

The key contributions of this article are threefold. First, it theoretically revisits the challenges of applying heterogeneous wireless networks on smart cities, raising questions related to the interoperability of wireless communication technologies. Next, it presents a heterogeneous, low cost and simple architecture for wireless communication and illustrates how the architecture can be employed by analyzing the key results obtained from experimental evaluations. Finally, it highlights open research issues, observed from the experiments.

This article proceeds as follows. Section 2 points out the challenges for developing heterogeneous wireless communication to smart cities. Section 3 describes the proposed architecture. Section 4 analyzes the key results obtained from the experimental evaluation of the architecture. Section 5 highlights open research questions. Finally, Section 6 concludes the article.

2. Revisiting smart cities and heterogeneity challenges on wireless communication

Wireless communication technologies have been a key feature to evolve smart cities. They are employed in different sectors of society, such as transportation, resources management and healthcare, producing diverse benefits. They allow real-time data diffusion among devices in the network, facilitating the monitoring and the control of devices and resources, such as energy and water. Wireless communication provides a fast access to remote information, improving quality of life. These technologies offer new services, such as real-time environmental monitoring, that lead to better decisions and actions by governments and enterprises.

Two key features of smart cities are their interoperability and the coexistence of different wireless communication technologies. These features have attracted considerable attention because they involve issues related to the design of heterogeneous wireless networks and their application in urban environments. These networks comprise devices (base stations, smartphones, ad hoc routers and others), different technologies and networks, such as wireless local area, ad hoc or vehicular networks [15].

Heterogeneous wireless networks present different challenges resulting from *interoperability* and intensified by their *application in smart cities*. Resource and network management, QoS (Quality of Service), security, reliability, load balancing and scalability are the main research issues in wireless networks yielded by these two aspects [16–18]. We briefly describe these issues, highlighting their effects.

- **Resource and network management:** In face of the expected heterogeneity, the opportunistic and efficient use of resources is essential. However, it is complex, since many aspects parameters and characteristics need to be considered. The direct application of optimization techniques to find the optimal setting for the network is a demanding task due to the dynamism of these networks and the existence of delay-sensitive applications, that require real-time decisions. Despite of heterogeneity, final users are concerned with financial cost, requiring a resource management that could keep the final cost low. Differently from other networks, heterogeneous ones need to deal with interferences caused by the diverse wireless communication technologies. Hence it is required new models and mechanisms that could be used for, respectively, analyzing and managing interferences, considering also urban environmental aspects.
- **QoS:** Providing high volume of data to multimedia applications for smartphones, tablets and other final user devices demand novel mechanisms to guarantee quality of service in face of the discrepancies of wireless technologies and network characteristics as scalability. Many services and applications offered by smart cities are sensitive to QoS. Examples are healthcare applications, such as long-term remote disease management or telesurgeries, or applications for smart grids and intelligent transportation systems.
- **Security:** Heterogeneity raises a high level of complexity for networks. New characteristics must be managed and more aspects need to be considered, intensifying existing security vulnerabilities on networks or producing new ones. On the other hand, smart cities provide applications and new services closer to final users. These cities have been instigated to improve the quality of life for residents and assist their daily tasks. Hence, in order to deal with new security vulnerabilities yielded by the complexity, security must be redesigned considering not only the weaknesses of wireless communication, but also the new characteristics resulted from this interoperable context. Mechanisms to deal with users authentication, accounting and authorization must be rethinking, as well as mechanisms to keep the availability of services and applications even in the presence of attacks. Furthermore, mechanisms for correctly identifying users and securely managing their identities, as identity management systems [19], are required, since it is expected a huge amount of final users using smart cities services and they need to be able to access them.
- **Reliability:** Heterogeneous networks must be sufficiently reliable to support features of multimedia applications and to provide a continuous service with few outages – one of the requirements of smart cities. Reliability ensures continuity of service for a specified period of time, and in general, is a period that is enough to reach the conclusion of the service. Guaranteeing reliability is a critical aspect in attracting and maintaining end users, as well as to achieve QoS. Services must be available anywhere and anytime for end users, since people are expected to be very dependent on the services as a result of the convenience ensured by smart cities [20].
- **Load balancing and scalability:** It consists in a way to achieve an efficient resource sharing over heterogeneous wireless networks. It can improve resource utilization, enlarge system capacity, as well as provide better services for users [18]. Load balancing depends on the network architecture and algorithms. However, smart cities can provide hybrid network architectures, which together with interoperability and complexity include new algorithms and solutions for dealing with heterogeneous network requirements and features, such as scalability.

3. The proposed architecture

Most of the existing solutions for integrating different wireless communication technologies and networks for smart cities depend on **expensive** equipment, and only few of them seek to create