Acoustic Wave-Based Wireless Data Communication in Urban Water Supply Networks

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Data communication through non conventional media is an increasingly relevant topic, especially in areas where traditional infrastructure might be unavailable or ineffective. Of particular interest is the case of infrastructure meant for the transportation of fluids, such as gas, oil or water. Such kind of plants provide a vast network of pipes which can be employed for communication purposes. The present thesis investigates the use of acoustic waves inside fluid-filled pipelines to transmit data from one point to another. The acoustic wave technology has been chosen thanks to its ability to propagate over long distances, as the application targets pipelines in urban areas where the energy consumption of the communication system is critical. A brief literature review is provided in order to highlight the area where the present work is situated. In particular, the research gap to which this research answers, is underlined. Then a simplified description of the physics of acoustic wave propagation is provided, with special attention to the case in which the acoustic medium is a liquid. The case of in-pipe acoustic propagation is described by means of the classical wave theory, which results in the introduction of propagation modes and modal analysis. Alternative techniques such as the transmission line model and the Finite Element Analysis are briefly described. Through simulations, a feasibility study is performed for the acoustic communication problem. The study highlights the dependence of the acoustic propagation on a large number of parameters, such as the structure of the pipeline and its physical characteristics. In this phase the electroacoustical transducers are modeled as two-ports, so as to obtain the required voltage and current levels in order to achieve signal reception at varying geometrical characteristics of the pipe. Due to the important sensitivity of acoustic propagation to physical elements that are difficult to model, like pipe bends, joints, branches, defects, etc, the present work proposes that the design of the system be carried out following an

experimental channel characterization phase, instead of theoretical modeling, which can only be applied in very simple cases. For this reason, a new design procedure is proposed, which adopts behavioral modeling of the acoustic channel by fitting the experimentally measured data. The advantage of the experimental characterization is that it captures all the features of the acoustic channel, which would be nearly impossible to incorporate in physics-based models. Moreover, the black-box modeling of the channel allows for system-level simulations, so that a suitable data-modulation scheme, tailored to the channel at hand, can be individuated. The proposed design approach has been applied to a real-world case study, consisting of a buried water pipe, which presents many of the highlighted characteristics such as bends, branches and multiple propagation paths. Based on the frequency response of the channel an OOK data modulation scheme is selected, as well as the carrier frequency and the data-rate so that the BER is minimized. As part of the channel characterization step, a system was developed in order to characterize spatially large channels without the need for long wires. The proposed procedure was demonstrated by a practical implementation of a communication system, which resulted in successful data transmission over a 70 m water-filled pipe segment, in presence of adverse phenomena such as signal reflection, attenuation and multi-path propagation.