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# Analysis of quantities influencing the performance of time synchronization based on linear regression in low cost WSNs

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ABSTRACT

Time synchronization is a key feature of Wireless Sensor Networks (WSNs). In low cost WSNs this is a very challenging issue since the general employment of a large number of nodes, characterized by low power and limited energy resources. Therefore, in such contexts, the adoption of synchronization algorithms is preferable to the adoption of GPS-based solution because of its high energy consumption, high cost and poor performance in indoor environment. An even increasing number of papers dealing with the design and the implementation of protocol-based techniques for synchronization can be found in literature.

These synchronization algorithms can be divided into three main categories: one way messaging, two ways messaging and consensus based synchronization. Among the others, those based on the one way messaging and, in particular, on the adoption of regressive algorithms are widely used in many application contexts. Focusing the attention on this class of synchronization algorithms, this paper proposes a deep performance analysis aimed at highlighting the sensitivity of the regression-based algorithms to some factors that influence the accuracy in typical low cost applications, such as the finite resolution of the local timing clock, the presence of clock drift, clock high frequency noise and low frequency noise, the presence of latencies due to the radio devices, the presence of latencies due to the microcontroller device. The main goal is to evaluate the effect of each one of these factors of influence on the overall synchronization performance. To these aims, suitable analyses both in simulation environment and on real nodes have been carried out.



## 1. Introduction

Wireless Sensor Networks (WSNs) pervade many of today industrial and user applications. In most of these applications wireless sensors are small and low cost devices, with limited energy and computational resources that operate in small scale areas where no further infrastructure is present [1,2] and have to "share" the same sense of time to obtain coordination among nodes, synchronized measurements, reliable data fusion, localization and environment monitoring to cite a few. Moreover, the sensor network efficiency is largely dependent on the time synchronization among nodes [3]. Since the requirements of low-costs, low energy consumption and indoor use, this task is typically entrusted by synchronization protocols rather than specific hardware solutions (like Global Position System, GPS).

Recent literature is proposing many efficient algorithms for WSNs synchronization [4–6]. In the wide number of proposals present in literature, those based on linear regression are greatly explored by researchers since the promise of very good performance and energy consumption. These

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algorithms synchronize wireless sensor nodes by establishing a linear relationship between clocks of different sensor nodes with the aim of predicting a reference clock based on collected time-stamps.

The authors are involved in the topics of WSNs and synchronization from some years. In particular, the attention has been focused on the implementation and performance characterization of WSNs when low cost wireless sensor nodes are used. New wireless nodes and wireless interface architectures have been designed in [7,8], as well as the performance of synchronization schemes, based on both two ways messaging and regression-based protocols, have been implemented and experimentally characterized [9–11].

These studies evidenced that in typical industrial and user applications, where time synchronization is performed by devices that do not have specific hardware features, and in real scenario characterized by non-ideal clocks, real communication channels and processing devices, the performance can greatly change respect to one expected.

Focusing the attention on regression-based synchronization protocols, this paper extends previous studies performed in [11] and proposes a methodological approach for analyzing the above-mentioned causes affecting the synchronization performance. Typical factors of low cost applications, such as the finite resolution of the timing clock, the presence of clock drift, clock high frequency noise and low frequency noise, the presence of latencies due to both the radio devices and microcontroller device have been considered. The aim is to evaluate the effect of each one of these factors of influence on the overall synchronization performance. In the following, after a brief theoretical background about the regression-based synchronization algorithm and the description of the timing model of a synchronization procedure, the main causes of influence are analyzed in detail and their effects are evaluated in a suitable simulation environment. Then, considering real nodes, a suitable set-up able to generate precise clock frequencies, to impose desired clock behaviors (i.e. variation of clock over time according the desired waveforms), to emulate fixed and variable latencies due to the communication channels, the serial tunneling and the application software has been adopted.

## 2. Main synchronization issues and factors of influence

### 2.1. Brief notes on regression-based synchronization protocols

Synchronization methods based on linear regression aim at achieving network wide synchronization between the local clocks of the participating nodes. Often these algorithms provide multi hop synchronization in which the root of the network manages and maintain the global time. All the other nodes synchronize their clocks to the one of the root.

The operating of a regression-based synchronization algorithm can be described as follows.

The sender sends a message that contains its own time-stamp. Receivers use the received time-stamp to generate their initial local clocks. Then the sender dispatches a number of time-stamps generally with regular time intervals. Each receiver compares the received time-stamp with that obtained from its local clock at the receiving time. If the corresponding drifts are linear (see Fig. 1), a regressive pattern may be predicted and used to compensate errors, thus reducing the updating rate. This class of synchronization protocols has the advantages of having low transmission loss and being robust at the temporary or persistent unavailability of some nodes, but it has the disadvantage of collecting more time-stamps to put into effect a linear regression.

### 2.2. Discussion on factors of influence

In real scenarios, synchronization protocols applied to real cheap wireless sensor nodes dramatically worsen their performance respect to that expected in theory [12–14].

Several factors of influence play a key role when real scenarios are involved. Among them, the most important factors concern with: (i) non-ideality of clocks that are characterized by drifts, high frequency noise and low frequency noise over time, (ii) the implementation on real low cost nodes (i.e. low cost microcontrollers without specific synchronization and time stamping features), (iii) the adoption of commercial radio systems with limited bandwidth and not negligible radio latencies, and (iv) the non-ideal behavior of the wireless channel.

In this framework, focusing the attention on the regression-based synchronization algorithms, it is expected that the number of collected time-stamps and the time interval among them could influence the overall performance.

As for the (i) point, real low cost wireless sensor nodes generally adopt commercial clocks that exhibit non-ideal behavior characterized by drift, timing high frequency noise and low frequency noise. These behaviors are influenced by the clock accuracy and by other environmental quantities of influence as temperature, power supply stability, electromagnetic noise and so on. Regression-based synchronization algorithms are developed to estimate and compensate skews and offsets among clocks but are not designed to recover the effect of timing high frequency noise and low frequency noise. As a consequence, these factors of influence have to be taken into account for compensating also such effects by selecting the number of time-stamps to be adopted in the regression algorithm and the time intervals among them.

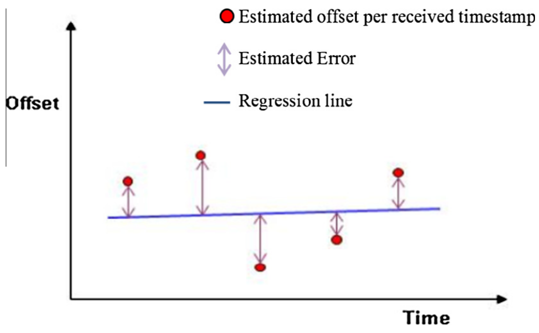


**Fig. 1.** Operating of a regression-based synchronization algorithm.