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Performance Analysis of Flooding Time Synchronization Protocol in Traffic Monitoring Scenarios

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***Abstract* – Many road applications as real-time traffic monitoring, vehicle counting and speed measurements, environmental and pollution monitoring along the roads, impose accurate time reference of detected events. In the most of the applications, measurement stations are based on distributed architectures in which one node acts as master and the others, defined slaves, have to be synchronized with the master. Generally, the master is equipped with a clock reference based on the Global Positioning System, while the slaves are synchronized with the master by the way of suitable synchronization protocols. Focusing the attention on such protocols, in a previousstage the authors analyzedthe effect, on the synchronization performance, of the finite resolution of the timing clock, the presence of clock drift, clock jitter and wander, the presence of real latencies of the radio devices and microcontroller.**

This paper extends the study by considering further factors of influence as the distance among nodes, the level of the transmission power, the receiver sensitivity and the effect of the environmental factors.

I. INTRODUCTION

Many road applications as real-time traffic monitoring, vehicle counting and speed measurements, environmental and pollution monitoring along the roads, to cite a few, impose accurate time reference of detected events and measurements. In the most of the applications involving wireless sensor networks (WSNs),suitable distributed architectures in which one node acts as master and the others, defined slaves, have to be synchronized with the master are adopted. Generally, the master is equipped with a clock reference based on the Global Positioning System (GPS), while the slaves are synchronized with the master by the way of suitable synchronization protocols.

Recent literature is proposing many efficient algorithms for WSNs synchronization [1]-[3]. In the wide number of proposals those based on the linear regression are greatly explored by researchers since theypromisevery good performance and adequate(for the context) energy consumption. These algorithms synchronizewireless sensor nodes by establishing a linear relationship between clocks at different sensor nodes with the aim of predicting a reference clock on the basis of the collected timestamps. The most popular protocol of this class of synchronization algorithm is the Flooding Time Synchronization Algorithm (FTSP) [3].

The authors are involved in the topics of WSNs and synchronization from some years. In particular, they have focused the attention on the implementation and performance characterization of WSNs when no-specific hardware featured architecture is considered as happens for low cost wireless sensor nodes. They have designed new wireless sensor nodes [4] and wireless interface architectures [5], as well as implemented and experimentally characterized the performance of synchronization schemes based on both two ways messaging and regression-based protocols [6]-[8].

Their studies evidenced that in typical industrial and user applications, where time synchronization is performed by devices that do not have specific hardware feature, real clock non-idealities and real communication and processing devices are present, performance can greatly change respect to that expected.

In a previousstage the authors proposed a methodological approach for analyzing the above-mentioned causes of influence affecting the synchronization performance. In particular, typicalfeatures of low cost applications, such as the finite resolution of the timing clock, the presence of clock drift, clock jitter and wander, the presence of real latencies of the radio devices and of the microcontroller have been considered.

This paper extends the previous study by considering other factors of influence as the distance among sensors, the level of the transmissionpower and the receiversensitivity, the effect of the environmental factors.

The aim is to weight the influence of each one of these factors of influence on the overall synchronization performance. The analysis is carried out in two stages the former in a suitable simulation environment and the latter on real nodes.

As for the latter, suitable set-up able to generate precise and controllable 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.

The final aim of the research is twofold. From one hand, the study will individuate techniques to mitigate the effect of these influence factors and, from the other hand it aims at the definition of a reliable uncertainty model able to characterize the synchronization performance.

II. THE PROPOSED ANALYSYS

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Synchronization performance directly depends on some factors of influence related to the employment of real sensor nodes and peculiarities of the application scenario. The following factors of influence play a key role when real scenarios are involved. They concern with: (i) the employment of real clocks, (ii) the implementation on real low cost nodes (i.e. low cost microcontrollers without specific synchronization features), (iii) the adoption of commercial radio systems (such as WiFi, BlueTooth, ZigBee) with limited bandwidth and not negligible radio latencies, (iv) the behavior of the wireless channel together with the transmission power and receiver sensitivity, and (v) the node position and mobility. In addition, with specific attention to the regression-based synchronization algorithms, also the number of collected timestamps 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 jitter and wander. This 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 able to recover the effect of timing jitter and wander.

As for the ii) point, low cost wireless sensor nodes generally do not feature an embedded radio-frequency (RF) device capable to generate timestamps at Media Acces Control (MAC) level. They usually communicate with external RF devices through serial tunneling (e.g. TTL-232, I2C, SPI, etc). These serial tunnels introduce additive latencies in communication ([9]-[11])that couldworsen the overall performance of the synchronization protocols. In addition, real low cost nodes adopt a finite resolution in the time measurement routines.

As far as the iii) point is concerned, typical radio systems adopted in WSNs as the WiFi, BT, ZigBee show variable latencies that coulddepend on the considered radio standard, the considered radio device, the number of devices present in the network and the network state [12]-[14].

As for the wireless channel (iv), the presence of interference due to the particular electromagnetic scenario could influence the performance causing both the loss of timestamp packets and the packet retransmissions. In addition the presence of multipath is a factor of influence to be considered as well. All these causes could influence the reliability, the packet transmission latency and the overall accuracy of the synchronization performance. As for the v) point, the distance among nodes, the mobility of nodes, together with the adopted transmissionpower and the receiver sensitivity could cause a number of messages to be retransmitted or lost. This can be seen as an additional variable, unwanted and uncontrolled latency which effect has to be adequately explored.

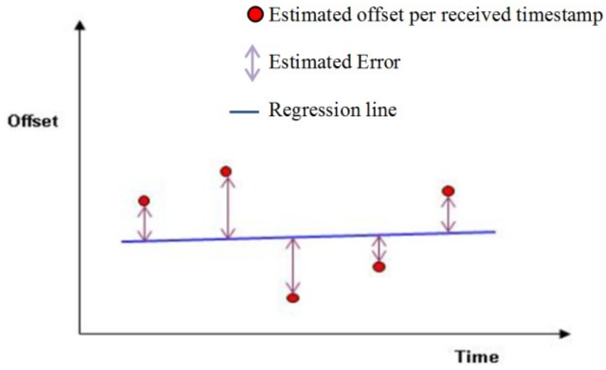

Fig. 1 Operating of a regression based synchronization algorithm.

In previous paper the authors have explored the effect of i) to iii) points[8]. In this paper they would explore the quantities of influencerelated to iv) and v), in order to assess the overall performance of this class of synchronization algorithm.

III. RESULTS IN SIMULATED SCENARIO

In the following a brief description of the adopted simulation environment together with the analysis of the explored parameters is reported.

A. The simulation environment

Asuitable simulator has been used to extend the work previous study to new factors of influence. Among different simulation environments for WSNs listed in [15], it has been chosenCastalia [16], [17]which is a simulator for WSNs (WSN), body area networks (BAN) andgenerally networks of low-power embedded devices. It is based on OMNeT++, "*an extensible, modular, component-based C++ simulation library and framework, primarily for building network, both wired and wireless, simulators*"[18]. It isdeveloped at the National ICT Australia since 2006 and made public as open source underthe Academic Public License in 2007.

B. The considered simulation parameters

This work propose to study the factors of influence, bound to the deployment of the nodes andto the transmission of the synchronization message, when the FTSP algorithm, one of the most used ad hoc algorithms for WSNs based on linear regression, is applied.The source code of the algorithm has been taken from [19].

The simulator Castalia models different aspects of a WSN from communication (from the wireless channel, including path loss model and presence of electromagnetic interference, to the radio behavior and the implementation of different MAC protocols) to physical process, the mobility managing of the node, the

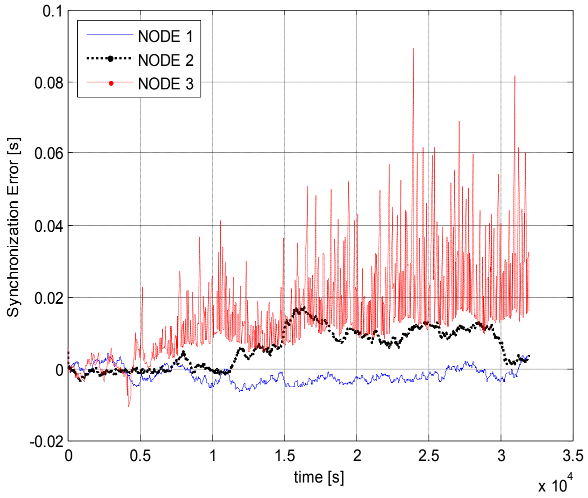

Fig. 2 Evaluation of the synchronization error for a maximum distance between the sender and the last communicating receiver of 3m at -25dBm of transmission power.

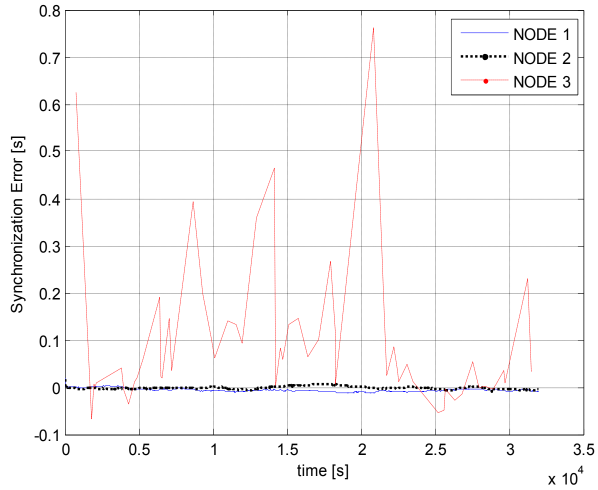

Fig. 3 Evaluation of the synchronization error for a maximum distance between the sender and the last communicating receiver of 15m at -10dBm of transmission power.

resource managing (as tracking the energy consumption of the node) [20], while the FTSP software improves the clock model provided by Castalia in order to make it more realistic adding the drift variation over time and its variability in different nodes.

Among the parameters provided in Castalia and in the algorithm, the authors focus the attention on the analysis of the synchronization precision as a function of both the distance of the receiver node from the sender node andof the transmission power (in an ideal environment).

C. First numerical results

The simulation has involved a configuration of 10 nodes, one transmitter and 9 receivers, equally distributed and aligned along a straight line. They communicate between them in an ideal outdoor environment, with no electromagnetic interference,where all nodes at a certain distance from a transmitter get the exact same signal strength and all links are perfectly bidirectional.For a fixed synchronization interval of 20s and simulation interval of 32000s (that corresponds to 1600 synchronizations), the performance of the FTSP implemented in the Castalia environment has been evaluated with respect to the transmissionpower and the distance between the sender node and the receivers. In particular, the first parameter was set at four different levels: 0, -5, -10, -25 dBm. For the second, 3 different distances have been chosen: 10m, 30m and 50m, where the distance between two consecutive nodes was respectively 1m, 3m and 5m, supposing the sender nodes at position 0m. For a sakeof clarity, the node indexed with the number 1 is the nearest to the sender node, while the node indexed with the number 9 is the furthest.

Fig. 2 shows the synchronization error for a transmissionpower of -25 dBm when the nodes are at 1m of distance from each other. It can be noticed that only the first three nodes, deployed respectively at 1m, 2m and 3m from the sender, succeed in exchanging the necessary timestamps to get synchronizedat this transmissionpower. The second aspect can be noticed in Fig 3: when the distance increases, at -10dBm and 5m of distance between nodes, the furthest node loses some synchronization message, increasing the synchronization error. In Table Iand Table II the mean value of the synchronization error for each node, for each transmission power respectively at 10m and 50m of distanceis also shown.They confirm the trends observed in Figure 2-3.In particular, synchronization performance worsen of order of magnitude as the transmission power decreases and the distance among nodes increases.

Other tests have been performed considering a realoutdoor environment, in presence of electromagnetic

Table I Trend of the mean value of the synchronization error for all nodes, for different transmission powersat a maximum distance of9m.

TransmissionPower	Nodedistance [m]								
	1	2	3	4	5	6	7	8	9
[dBm]	μ [s]	μ [s]	μ [s]	μ [s]	μ [s]	μ [s]	μ [s]	μ [s]	μ [s]
0	1.0179E-02	1.8008E-03	3.9347E-03	5.2473E-03	-2.2004E-04	9.4087E-04	2.1555E-03	2.8362E-03	4.9845E-03
-5	3.7651E-03	1.7404E-03	1.9725E-03	5.0062E-03	-2.2919E-04	3.4834E-04	4.9391E-03	2.1741E-03	5.5770E-03
-10	2.0446E-03	3.2145E-03	4.5924E-03	5.2327E-03	3.8599E-03	1.1828E-03	7.5923E-03	2.4563E-04	-1.4075E-03
-25	-1.9172E-03	5.6698E-03	1.3243E-02						

Table IITrend of the mean value of the synchronization error for all nodes, for different transmission powersat a maximum distance of45m.

TransmissionPower	Nodedistance [m]								
	5	10	15	20	25	30	35	40	45
[dBm]	µ [s]	µ [s]	µ [s]	µ [s]	µ [s]	µ [s]	µ [s]	µ [s]	µ [s]
0	-1.0283E-03	4.1455E-04	9.9487E-04	2.3310E-03	3.1938E-03	5.3649E-03	7.2361E-03	-4.0557E-03	-3.4174E-03
-5	-2.5507E-03	2.0215E-03	3.8132E-03	-3.5205E-03	4.4545E-03	2.5277E-03	-1.1512E-03	6.5981E-03	5.0192E-04
-10	-5.8816E-03	-1.2434E-03	8.7881E-02						
-25									

interference,variation of the signal strength and not-perfectly bidirectional links.

Results are reported in Figures 4 and 5. It is possible to highlight the worsening of the performancerespect to the cases of figures 2 and 3.

IV. CONCLUSIONS

A preliminary characterization of synchronization algorithms based on linear regression and operating on low costs wireless sensor nodes has been carried out when traffic monitoring scenarios are considered. The effect of influence factors as the transmission power, the distance and the quality of the radio channel have been analyzed. The achieved results have highlighted the effect of each of the above mentioned influence factor and have demonstrated as the performance of these protocols in such scenarios may drastically change from what expected.

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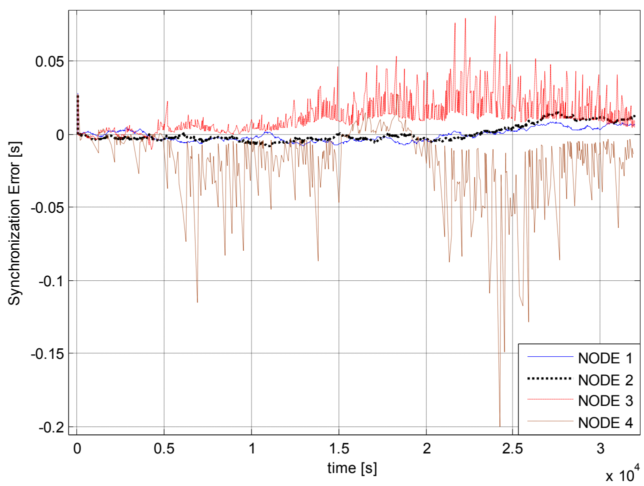

Fig. 4 Evaluation of the synchronization error for a maximum distance between the sender and the last communicating receiver of 4m at -25dBm of transmission power. The real channel is involved.

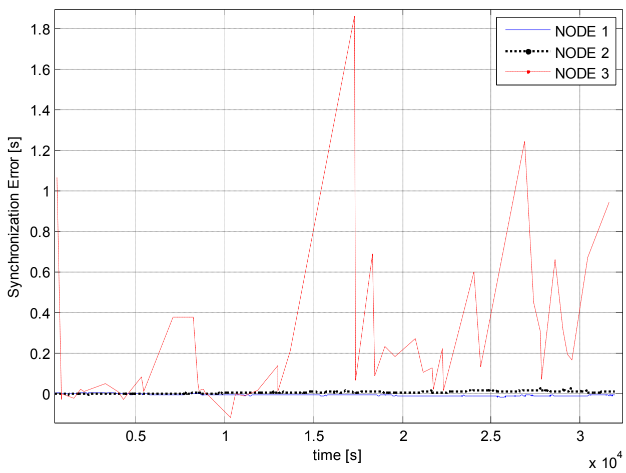

Fig. 5 Evaluation of the synchronization error for a maximum distance between the sender and the last communicating receiver of 15m at -10dBm of transmission power.

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