AVERAGE CONSENSUS IN WIRELESS SENSOR NETWORKS WITH PROBABILISTIC NETWORK LINKS

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ABSTRACT

This study proposes and evaluates an average consensus scheme for wireless sensor networks. For this purpose, two communication error models, the fading signal error model and approximated fading signal error model, are introduced and incorporated into the proposed decentralized average consensus scheme [1]. Also, a mathematical analysis is introduced to derive the approximated fading signal model from the fading signal model. Finally, different simulation scenarios are introduced and their results analysed to evaluate the performance of the proposed scheme and its effectiveness in meeting the needs of wireless sensor networks.

KEYWORDS

Wireless Sensor Network, Mobile Ad Hoc Network, Analog to Digital Converter, Radio Frequency Intelligent Transport System, Approximated Fading

INTRODUCTION

In recent years, major advances in wireless communication and digital electronics led to the development of tiny sensors that can broadcast sensed data over short communication ranges. A wireless sensor network (WSN) is composed of a number of sensor nodes that have sensing, processing and communication components that enable all the network nodes to collaborate in order to achieve a particular task. Each node in a WSN is designed to have limited computational and power capacities and use basic broadcast communication protocols in order to exchange information with its neighbours. Moreover, sensor nodes are designed to be densely and randomly deployed very close to the phenomenon that the WSN is expected to monitor [2]. This allows WSNs to be used in a wide range of applications where the exact position of each sensor cannot be pre-determined and the nature of the topology makes more sensors prone to failure. Many problems often arise in WSNs due to their network architecture, environments where they are deployed or the computational and power limitations of their nodes. The network nodes are often exposed to harsh conditions, like the ones experienced in a battlefield, or may run out of power after a short period of time, which means that the network is going to be losing nodes over time [3]. Also, the modest computational power of the nodes will impose certain constraints on the algorithms that are going to be implemented in the network in terms of computational requirements, memory storage capabilities and computational efficiency. Consequently, the algorithms implemented in the network need to work in a decentralized manner in order to minimize the effect of losing nodes on the network functionality. Other problems experienced in WSNs are similar to those found in all ad hoc mobile wireless networks like communication errors, hidden terminal problem, exposed terminal problem, etc [4].

This study introduces a new average consensus scheme that takes into consideration the constraints of WSNs in terms of communication errors. The consensus algorithm and the weighting scheme used in this study were adopted from previous studies on this topic because of their e effectiveness in achieving average consensus in a decentralized manner, thus overcoming some of the constraints found in WSNs as mentioned earlier [5]. Several simulations were carried out to illustrate the proposed consensus schemes.

METHODS AND MATERIAL

Two wireless communication error models are introduced. The first one is the fading signal error model and the second is the approximated fading signal error model, where the latter is derived from the former. Also, mathematical analysis [6] in introduced to support this derivation and its significance is discussed in terms of different factors relevant to the problem introduced.

RESULTS AND DISCUSSION

1.The Significance of the Approximated Fading Signal Error Model

Introducing the fading signal error model to the proposed average consensus scheme was very relevant to WSNs. Furthermore, approximating this model was important for several reasons. First, it simplified the theoretical analysis of the proposed scheme by eliminating the need to consider the inter-nodal distance of each pair of neighbouring nodes in the WSNs by taking advantage of the uniform random spatial distribution [7] of the WSN nodes in the topology. Second, as each node in a WSN may not be able to measure the inter-nodal distance with its neighbours, it provides a means for it to predict whether a certain transmission is going to be delivered to a certain neighbour or not. If a given node predicts that the transmissions is not going to succeed, then it will defer it for later thus reducing the network overloading. Third, keeping track of delivered transmissions might give the node an idea about the rate to convergence and may allow it to predict when will the average consensus algorithm halt.

2. The Metropolis Weighting Scheme and the incorporated Communication Error Models

In all the simulations that were carried out, node state values converged to the average consensus value, which is the average of all initial state values of all nodes. This is because the Metropolis weighting scheme allowed each node to generate weights for their different communication links for each iteration of the consensus algorithm that kept the overall weight matrix of the network doubly-stochastic over time, which is the property needed to converge to average consensus. None of this required any node in the network to collect information about the topology or store any historic data. This enabled the average consensus algorithm to operate irrespective of topology changes induced by communication failures, power depletion in nodes, etc.

3. Rate of Convergence to Average Consensus

Fig. 1 shows that the number of iterations to consensus and the corresponding computed convergence time are linearly related. First, this illustrates that the rate of convergence to average consensus as measured by the average of the spectral radii of the weight matrices formed during the different epochs of the average consensus algorithm accurately measures the performance of the average consensus algorithm. Second, this relationship provides a way to predict the number of iterations the average consensus algorithm is going to run in a certain period of time given a network with a certain algebraic connectivity [8]. Third, it shows that the algebraic characteristics of the graph representing a network can be used to estimate how many iterations the algorithm is going to run given a certain topology.

However, the convergence time does not take into consideration the propagation time of wireless signals and the processing times of the nodes. In a real-world scenario, this will definitely increase the rate of convergence to consensus.

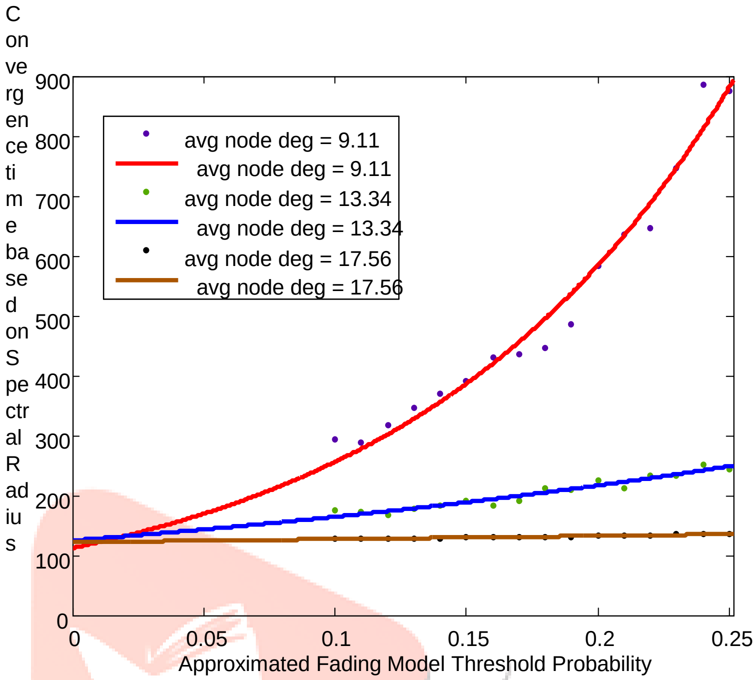

Fig. 1.: Convergence time vs. AF Model threshold probabilities γ

4. Suitability of the proposed Scheme to WSNs

Power is one of the most critical constraints in WSNs. Thus, any proposed WSN algorithm or protocol must take into consideration minimizing the power consumption of the WSN. Also, it was clarified earlier that the power of the WSN is mainly consumed in processing, communication and sensing, where communication is the most significant power consumer. The simulations that were carried show that the number of iterations needed to reach average consensus is smaller than those needed by other proposed schemes such as. Moreover, each node only needs to communicate its state-value, ID, in-degree and out-degree, which is a relatively small amount of data. Also, the proposed scheme does not require any node in the WSN to run any lengthy or complex computations to calculate the average consensus value [10] or the communication links' weights. This will significantly reduce the power consumption of each node.

Another issue that is usually taken into consideration in WSNs is the scalability of the network. Since the Metropolis weighting scheme does not require any node in the WSN to store any information about the topology or about the other nodes, the proposed scheme should work the same way for both small and large networks. However, large WSNs deployed in a small topology will generate a larger node density. This could possibly lead to overloading the WSN as all nodes will be competing to broadcast their state- values concurrently.

CONCLUSION

Summary

In summary, a decentralized scheme to compute the average consensus of the initial values of all nodes in a WSN was introduced. Also, two different error models, the fading model and the approximated fading error model, were introduced to describe the probability of establishing communication links between the neighbouring nodes. It was shown that the proposed scheme enabled all nodes to converge to average consensus.

However, the number of iterations needed to converge to consensus was greater when the error models were incorporated as compared to the error-free scenarios. Furthermore, it was shown that the fading model was the most realistic one in modelling the communication errors that usually occur in WSNs and that the approximated fading error model can possibly approximate the fading model.

The advantage of using the approximated fading error model is that it simplifies the mathematical analysis of the convergence to consensus as it eliminates the need to take the inter-nodal distance parameter into consideration. Also, from an implementation point of view, the approximated threshold probability γ *[11]* that the approximated fading error model provides can help a given node in the network predict whether its transmission at a particular epoch is going to succeed or not. If the node determines that the transmission is going to fail, then it can defer the transmission for some time to reduce transmission collision and improve network throughput.

Moreover, the analysis of the simulations introduced has shown that increasing the value of γ is going to impact the number of iterations needed to converge to average consensus. This will not be as significant on networks with high average node degree as compared to others with lower average node degree [12].

The same results were obtained in terms of convergence time, which is calculated using the average spectral radius of the weight matrix of the WSN. However, the simulations that were carried out have shown that the relationship between the number of iterations to average consensus and convergence time based on spectral radius is linear for networks with high average node degree and almost logarithmic for networks with lower average node degree

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