Ad Hoc Networks 54 (2017) 17–29

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Neural networks and SDR modulation schemes for wireless mobile nodes: A synergic approach

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ARTICLE INFO

Article history:
Received 8 October 2015
Accepted 16 September 2016
Available online 22 October 2016

Keywords:
Self-organizing networks
SDR
Controlled mobility
Neural network
Genetic algorithm

ABSTRACT

In this paper, we envisage the possibility to exploit, in a synergic way, the Software Defined Radio (SDR) capability and the mobility support for wireless devices to dynamically compute the most suitable modulation scheme and the best position in order to improve both the coverage and connectivity in a specific area. The combined approach is based on a *Neural/Genetic* technique and wireless nodes are able to self-organize in a totally distributed way by using only local information. The extreme adaptability to the network conditions and application level constraints makes the proposed approach well suited for different communication scenarios such as standard monitoring or disaster recovery. The system performance has been evaluated by dealing a suite of simulation tests to show as the controlled mobility paradigm, coupled with the intrinsic re-configuring SDR capabilities of such wireless devices, allows to increase the network performances both in terms of coverage and connectivity by dynamically adapting the modulation schemes to the specific communication scenario.

1. Introduction

Very recently, the idea of designing new communication devices, capable to adapt their operation roles in a self-organized fashion to rapidly face the changes within the working environment, has gained a very high attention from the wireless network research community [1,2]; similarly, the availability of novel general purpose and powerful hardware platforms able to be dynamically reconfigured via software [3], has paved the way for new research directions in which it is possible to deploy extremely challenging communication scenarios [4,5].

Being inspired by this novel communication trend and, taking into account the unique features offered by the recent *Software Defined Radio (SDR)* paradigm as envisaged in [6,7], we considered the design of a self-adapting deployment strategy for a communication network in which several wireless devices, scattered all around in a specific area, can carry out a common task according to specific network requirements in terms of coverage or connectivity. In this context, aiming at handling very unlike communication scenarios, we firmly believe that, the SDR capabilities of future wireless devices can be effectively improved by coupling them with the potential offered by a wise *controlled mobility* strategy to exploit different reconfiguration and self-adaptation levels.

By following this first intuition, the paper proposes a distributed *Neural/Genetic* algorithm to compute the final nodes positions and the more performing modulation schemes for each transmitter/receiver pair in order to guarantee an agreed QoS level. The potential of using genetic algorithms to solve cellular resource allocation problems has been considered in [34]. In particular, in our work, by considering a generic SDR architecture [8–10] the major advantages consisting into the ability of automatically selecting the more suitable modulation scheme to be used for an unknown received signal, can be effectively achieved. Thus, as a channel capacity varies, modulation scheme switching enables the baud rate to be increased or decreased in order to maximize the channel capacity usage. In addition, as demonstrated in our preliminary studies [13], SDR capabilities supported by a wireless node, coupled with the controlled mobility functionality, can improve the overall system performances in terms of connectivity. Therefore, such mobile SDR nodes turn out to be very useful for communication scenarios in which, the requirements on constrained QoS connectivity, are more stringent respect to the ones on the maximum coverage.

An example of such communication scenario could be the case of a *disaster area* where the communication between the survivors and the rescue teams has to guarantee a good quality level [11,12];

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http://dx.doi.org/10.1016/j.adhoc.2016.09.016
1570-8705/

on the other side, a communication scenario mostly related to applications such as *pollution monitoring* or *fire detection* only need a high coverage degree that can be achieved by taking advantages just from the mobility of the nodes without using the SDR capabilities.

In summary, we made the following contributions in this paper:

- we discussed the potential of mobile SDR communication devices in terms of both dynamical re-configuration and operation flexibility;
- we shown how the SDR capabilities supported by the wireless node, coupled with the controlled mobility functionality driven by a distributed Neural/Genetic, can improve the system performances in terms of connectivity by also guaranteeing an agreed QoS level;
- we designed and validated an optimization model in order to prove, in a mathematical way and on a very simple communication scenario, the goodness of the proposed Neural/Genetic algorithm before to conduct a more complex and intensive simulation analysis;
- we validated, throughout a self developed simulator based on a widely used open source framework for evolutionary design, the proposed strategy in different communication scenarios by varying both the amount of mobile and SDR nodes to measure the impact of a larger number of Mobile/SDR nodes on the overall system performances.

The rest of the paper is organized as follows: Section 2 presents few recent research works on deployment techniques for wireless nodes and adaptive modulation schemes implemented via SDR. Section 3 describes which technologies and specific features the devices involved in the proposed communication scenario should support, by highlighting hardware and software capabilities. Section 4 presents the Neural/Genetic algorithm able to compute the best positioning for the wireless nodes to satisfy the constraints imposed by the specific communication scenario. Section 5 presents the proposed optimization model to describe and validate the system behavior from a mathematical point of view. Section 6 discusses the obtained results and the goodness of the proposed approach in terms of extreme adaptability in different communication scenarios, whilst the conclusions and future research directions have been drawn in Section 7.

2. Related works

In this work we envision two main topics: 1) deployment techniques for different communication scenarios and 2) adaptive modulation schemes for nodes equipped with SDR capabilities. From the synergical combination and integration of *Neural* and *Genetic* approaches, we designed an algorithm able to compute the best position and the most suitable modulation scheme for each node involved into the communication path. According to these remarks, we first recall few contributions on positioning techniques for wireless nodes that have attracted much research attention becoming increasingly important in recent years. In [28] the authors try to outline the main criteria that should be considered while deploying wireless nodes in a sensor field. Fundamentally, they give an overview of multi-objective approaches by outlining the main assumptions and the formulation of this challenging problem. In [29], the author argues that the communication holes in wireless networks is the main problem causing inefficiency; thus it needs to be effectively addressed. More precisely, sensor nodes can be moved from an initial "unbalanced" state to a "balanced" state, where the number of communications holes is minimized. In [30] the authors distinguish placement approaches by considering deterministic and non-deterministic techniques. Often, non-deterministic placements are also named as random placements, while deterministic placements are referred as controlled placements and the authors refer to the two approaches by keeping this kind of assumption. The choice of how to deploy the sensors in a field, is often affected by the specific application, the type of sensors, the environment in which the sensors operate, etc. The possibility to control a node deployment can be extremely advantageous in terms of operational costs. Based on this last consideration, we figure out to equip wireless nodes with motion capabilities in order to make them able to move towards specific and more convenient locations by obtaining a dynamic changing of the topology/deployment. In this way, it could be add more control to the network and consequently outperform the operational costs. Generally, the survey we cited above, group the deployment techniques based on some specific network parameters such as coverage, lifetime, connectivity, or two or more of them together, but do neither consider at all the possibility for the nodes to autonomously move towards a specific position nor to adapt the modulation scheme to some specific requirements. In this work we consider the possibility to "change" the modulation scheme in order to guarantee a certain Bit Error Rate (BER) level, and in case this constraint can be satisfied by selecting more than one scheme, we select the most efficient in terms of energy consumption. For this reason, the contributions that compare modulation schemes selection to increase coverage and/or connectivity are considered also as related work. In [13] we present the preliminary idea to opportunistically select the more appropriate modulation scheme in order to achieve a certain degree of coverage and connectivity. The added value in respect of [13] is first of all in terms of a general benchmark definition, computed through the formulation of the combined coverage and connectivity problems as a multi-objective optimization problem. Moreover, we provide more details in terms of results by validating the algorithm we propose in several communication scenarios. Starting from 2007, Stuckmann and Zimmermann [31] envisaged SDR technology as one of the four main objectives, to develop European technologies for systems beyond 3G. Specifically, the spectrum and resource management to make efficient the use of existing spectrum resources can be realized in an feasible and effective way through the application of the SDR concept. The importance of this kind of technology is shown in [32], where the authors propose to optimize the throughput of the network, working in different channel conditions, by considering an automatic modulation switching method to reconfigure the transceivers of SDR systems. We propose a similar approach but with a different purpose, namely a multi-objective algorithm where the goals are both the coverage and the connectivity, in addition the technique is also energy-aware because, where more solutions are feasible, the best one in terms of energy-consumption is selected. Finally, in [33], the authors analyze different modulation techniques in combination with SDR. In practice, they outline again the importance of this kind of technology for the future mobile communication systems.

3. Smart mobile devices supporting SDR

New powerful devices supporting SDR capabilities will be used in the next future to form a self-evolving wireless network in which several goals such as coverage increase, high data rate and connectivity will be achieved in diverse communication scenarios. For this reason, with the aim of considering a quite modern communication context, we studied the case in which both simple mobile or fixed sensor nodes equipped with a wireless IEEE 802.15.4/ZigBee compliant RF transceiver, are considered. Furthermore, we also took into account the presence of more complex mobile devices, with a high processing capability, able to dynamically change the modulation scheme between different transmitter/receiver pairs by using the SDR support as shown in Fig. 1. In