

DARP: dynamic and adaptive radio protocol for wireless sensor networks

F.J. Estévez, G. Rebel, J. González and P. Gloesekoetter

The dynamic and adaptive radio protocol (DARP) is a new protocol proposal with some interesting features such as dynamic roles and the use of virtual sub-networks. The wireless sensor network state of art is discussed and some desirable features are presented in order to adapt these networks to new scenarios. These necessities are quite important to expand the applicability of wireless sensor networks and for this reason the DARP is proposed.

Introduction: 'Wireless sensor networks' (WSNs) usually refers to networks composed of devices with low-energy consumption and low data rates. Low-power wireless networks are constantly being extended, increasing the number of devices per network. Concepts like Internet of things or Smartcities consider thousands or millions of devices, and to achieve this purpose it is necessary to use techniques and mechanisms that provide an organisation level, failure tolerance, security and autonomous work as higher as possible. WSNs is an area with several protocols such as ZigBee [1], 6LoWPAN [2], EnOcean [3] or DASH7 [4]. These are used everyday, although they present problems that should be solved in order to be used in massive WSNs. The main reason to design and develop the dynamic and adaptive radio protocol (DARP) is to avoid some of these problems.

State of the art: Nowadays, WSNs is one of the main research topics. These researches are mainly focused on the number of devices that can be connected to one network, energy harvesting in order to improve the lifetime of the network nodes, improvements in data rate, and interoperability and techniques about how to manage millions of devices.

Most of these necessities are covered by the IEEE 802.15.4 standard [5], which provides some common features to the protocols that are behind WSNs. IEEE 802.15.4 provides physical (PHY) and media access control (MAC) layers and it works on the 868 MHz, the 915 MHz and the 2.4 GHz bands. The number of available channels changes depending on the frequency used: 1 channel on 868 MHz, 10 on 915 MHz and 15 on 2.4 GHz. The data rates are increased in each revision of the standard and also change with the modulation used. This standard defines two different kinds of device, full function devices (FFDs) and reduced function devices, and two topologies too, star and point to point, causing most of 802.15.4-based networks to use a central node that manages the network, although it allows the addition of more topologies over the network layer (NWK) to provide more features to the WSN.

Two of the more common topologies that many protocols implement over 802.15.4 are the mesh and the cluster tree. The main advantage of the mesh topology is that it allows connections between all nodes in the network, although it has some penalties with the energy consumption and the traffic on the network because it is necessary to maintain the network nodes in the active state for more time to send messages and maintain the links, thus increasing the traffic too.

On the other hand, the cluster tree topology enables one to define a hierarchy to manage the network, minimising the number of links to be maintained and thus the energy consumption, mainly because the traffic is lower and the nodes can sleep for more time. Nevertheless, as the number of links is minimised, it may be necessary to use more jumps to connect the two nodes belonging to different clusters.

However, IEEE 802.15.4 presents some strengths and vulnerabilities that are inherited by all protocols based on it. Its main strengths are scalability, robustness and configuration possibilities. Scalability because it allows organising the network nodes into several levels, letting each level administrate hundreds of devices. Robustness because the links between the nodes must be checked periodically. Configuration possibilities are considered because there are some options, like the network address type, the number of jumps or its security options etc., which can be modified.

The main weakness of this standard is the need to maintain one main FFD node to handle the complete network [6]. This drawback limits significantly the possibilities of using this standard to deploy massive networks, as the density and the extension of communication channels reach one point that makes the main node unavailable. Another

significant limitation relates to the maximum number of devices within a network, since the network performance decreases as the number of nodes is increased. There are also problems related to the network balance and to the addition of new devices to the network without control.

As stated above, IEEE 802.15.4 is the basis of the majority of the proposed WSN protocols and network techniques, ZigBee and 6LoWPAN-RPL being two of the most widely used. On the one hand, ZigBee defines three network roles: coordinator, router and end node, and provides mesh and cluster tree topologies. It also establishes a well-defined application framework and allows the deployment of networks with thousands of devices. Its main advantage is a significant reduction in the energy consumption of the network, but it has some drawbacks:

- *Orphan nodes:* It is not guaranteed that the devices are joined to the network, even if there are unassigned addresses in the network [7].
- *Guaranteed service time:* The network size should be small enough (not more than 40 nodes) if it is necessary to maintain a guaranteed service time under the superframe time duration [8].
- *Real-time applications:* Time delays to access buffers can affect applications with strict time limits, even in small networks [9].
- *Coordinator node's bottleneck:* This is the most serious problem in ZigBee networks. It appears when networks become very large, deteriorating the 'quality of service' and even causing 'denegation of service', resulting in a network collapse.

On the other hand, 6LoWPAN allows the compression and the splitting of IPv6 packets over 802.15.4 and it also provides a mesh topology. It defines an adaptation layer that provides some key elements:

- *Header compression:* The IPv6 header is deleted when its information can be extracted from the MAC layer. It also avoids maintaining redundant information on the headers through all the layers of the network protocol.
- *IPv6 fragmentation:* The IPv6 packets are split into several MAC frames in order to be compatible with the maximum transmit unit defined in IEEE 802.15.4.
- *Message forwarding:* The right address for the link layer is determined at the end of a jump.

6LoWPAN also presents some disadvantages [10]:

- *Routing protocol for low power and lossy networks (RPL):* This routing protocol allows having a node operating like a coordinator node in the ZigBee protocol. However, in 6LoWPAN-RPL this node is chosen using a voting mechanism that requires switching off and on the whole network each time a selection must be done.
- *High-energy consumption:* As a consequence of the voting mechanism and the maintenance of a mesh topology.

This Section has presented the strengths and weaknesses from IEEE 802.15.4, ZigBee and 6LoWPAN-RPL. The following Section depicts a new network protocol proposal.

The DARP proposal: The DARP protocol is also based on IEEE 802.15.4, although it presents a flexible and dynamic architecture intended to solve most of the drawbacks of ZigBee and 6LoWPAN-RPL described above. Its key feature is the application of the sub-network concept to the WSN, based on a cluster tree topology with two objectives in mind: an improvement of the network organisation and a reduction of the network traffic. The result is a protocol providing an easy sub-networks management with the following interesting characteristics:

- *Dynamic role adaptation mechanism:* There are three different roles: coordinator, router and leaf, all of them being based on the IEEE 802.15.4 FFD specification. The role of each node within the network is not set *a priori*, before the network is deployed. It is defined dynamically according to a predefined threshold based on a link quality indicator or LQI (1). As an LQI is transmitted on every IEEE 802.15.4 frame and it is based on the energy detection process that every device makes autonomously, this mechanism allows the adaptation of the network topology to changing scenarios, improving dynamically

the quality of the communications between nodes. As an example, the following thresholds could be used to determine the role of each node:

$$\begin{aligned} &\text{router if } 25 < \text{LQI} < 200 \\ &\text{leaf if } 200 < \text{LQI} < 250 \end{aligned} \quad (1)$$

- *Support of virtual sub-networks:* When a node becomes a router, a new virtual sub-network is generated. At this point, a router works as a coordinator node for this virtual sub-network, sending messages to its previous level only when necessary. It is also possible to limit the number of nodes that a determined router can accept. Fig. 1 depicts these concepts.

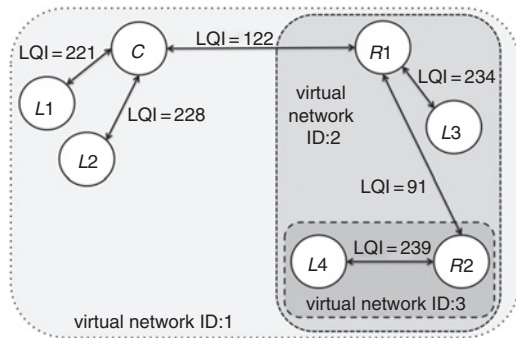


Fig. 1 DARP typical network structure

Communication between virtual coordinators and the real coordinator is performed just to maintain the network integrity. Another advantage of organising the network into virtual sub-networks is the possibility of using virtual sub-network addresses to send messages to one virtual network, instead of using nodes addresses directly; thus reducing the processing time needed to forward the message. Once the virtual sub-network is reached, the final node address is evaluated.

Preliminary tests: As preliminary tests have been focused on demonstrating the viability of this protocol, and also all the properties described before, there are no comparative results at this point. An AT91SAM3S Cortex M3 with an AT86RF212 radio transceiver from Atmel has been used as a test platform. The connectivity, availability and organisation of the network have been made successfully. A sniffer has been used to analyse the network traffic while a noise generator was creating interferences on the medium. The results show an average connection time of 0.9 s for one node, and a global average connection time of 5.4 s for a small network with five devices, communication, sleeping devices and virtual sub-networks auto-organisation.

Conclusions: This work has presented DARP, a promising network protocol intended for large-scale WSN massive device scenarios, which provides several improvements over ZigBee and 6LoWPAN-RPL. Its key feature is its self-organisability, which allows for adapting the quality of the connections and expanding the limits of the network to

connect more devices dynamically. Moreover, the organisation of the network into virtual sub-networks achieves a significant reduction of the traffic on the network and improves the detection and treatment of errors. Virtual sub-networks are designed to continue working autonomously in the case of errors in global communications. It is also possible to sleep devices for a longer time, since keep alive signals are collected and sent by the virtual sub-network, instead of by the device, thus minimising the traffic and reducing bottlenecks.

Next, we intend to simulate this protocol in an environment with millions of devices, and to compare its behaviour with the other protocols.

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One or more of the Figures in this Letter are available in colour online.

F.J. Estévez, G. Rebel and P. Gloeskoetter (*Department of Electrical Engineering and CS Semiconductor and Bus Laboratory, University of Applied Sciences of Muenster, Steinfurt, Germany*)

E-mail: fjestevez@ieee.org

J. González (*Department of Computer Architecture and Technology, University of Granada, Granada, Spain*)

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