Selection of the Wireless Communication Topology using IEEE 802.15.4 Standard

JAVIER BILBAO, EUGENIO BRAVO, CONCEPCIÓN VARELA, OLATZ GARCÍA, MIGUEL RODRÍGUEZ, PURIFICACIÓN GONZÁLEZ
Applied Mathematics Department
University of the Basque Country, UPV/EHU
Engineering School, Alda. Urkijo, s/n, 48013 - Bilbao
SPAIN
javier.bilbao@ehu.es eugenio.bravo@ehu.es concepcion.varela@ehu.es olatz.garcia@ehu.es
m.rodriguez@ehu.es purificacion.gonzalez@ehu.es

Abstract: - In Wi-Fi networks it always exists, as a basic structure, a communication manager and a number of clients. Clients will always listen for the presence of one or more managers who tell them, among other information, the name of the network that they manage, the channel to use, the security and available authentication algorithms, etc. Based on this information and settings of the device in question, the client will be able to join the appropriate network. In our project, where we develop a communication system among students and teacher into a classroom, we use ZigBee protocol based on the IEEE 802.15.4 standard. Different topologies can be used with this purpose and in this paper several of them are analyzed. Among them, we have selected the nonbeacon-enabled cluster tree.

Key-Words: - ZigBee, wireless network, network topology, protocol, communication.

1 Introduction

Wireless Sensor Networks (WSN) are made up by autonomous distributed nodes. The nodes include sensors to monitor physical or environmental parameters and a radio transceiver for transmitting and receiving information. These networks are based on packet switching, so that each block of information is fragmented into transmission small units called packets [1], [2], [3].

Today such networks are used in numerous applications. Some examples include monitoring and control of industrial processes, monitoring medical applications, monitoring of environmental variables, home automation, traffic control, etc. [4], [5].

The nodes must be very simple in hardware and user interface components. In addition to be equipped with one or more sensors, each node features:

- A radio transceiver or other wireless communication module.
- A low-power microcontroller.
- A battery.

The nodes of this kind of networks must be robust to allow its implementation in adverse environments, they must have low power consumption and manufacturing must be economical.

Regarding to the communications module (radio transceiver), IEEE 802.15.4 - 2006 standard defines the medium-access control layer (MAC) and the physical layer (PHY). This is the standard used by ZigBee. It is a specification for low-power mesh networks, promoted by a broad consortium of industry promoters (ZigBee Alliance). ZigBee includes IEEE 802.15.4 standard for the lower layers of the protocol stack [6].

2 Smartpens into the classroom

The importance of handwritten notes is similar and it is a constant. Pen and paper are still the main tools used by pupils in class for several good reasons: pen and paper are cheap, flexible, easy to use, and not distractive.

But digital pen technology is now a real alternative to the couple pen and paper. Among all the different cases, classes, and types of uses and technology that can be used, we have focus on the smartpen.

Our aim is a low-cost, novel, easy-to-use electronic platform that enables teachers to provide handwritten and spoken feedback to their students on their homework assignments, as well as

immediate assessment for the whole class. The assessment is done using an innovative system that enables all class students to answer the teacher question using their digital pen, while the system evaluate all the answers and print out the grades of all students on the spot [7].

The main pillar of the platform is a digital pen, which will be a new ergonomically designed input device that captures your handwriting without the need for special paper or a direct wired connection to a computer. You then can write notes anywhere and send it wirelessly to a screen or upload the files to your computer any time. It is the perfect merger of our most natural form of creative expression, pen on paper, with the modern need to digitize everything.

In our case, the communication network has three types of nodes: there will be, in a typical classroom, several students each of them with their smartpen; the same number of clips that will act both as receiver for the data transmitted by each smartpen and transmitter to the teacher's computer with the data of each student; and the computer of the teacher to receive students' data and save them to be evaluated.

3 IEEE 802.15.4 Standard

IEEE 802.15.4 standard defines the specifications of the physical layer (PHY) and of the medium-access control (MAC) layer for wireless connections with low data rate, in single low-power nodes operating in a usually range coverage of 10 meters. Therefore, it is a standard designed specifically for low power wireless personal area networks (LR-WPAN).

ZigBee is one of the newest technologies enabling Wireless Personal Area Networks (WPAN). ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard. The technology is intended to be simpler and cheaper than other WPANs, such as Bluetooth. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption. Though WPAN implies a reach of only a few meters, normally 10 meters, the network will have several layers, so designed as to enable intrapersonal communication within the network, connection to a network of higher level and ultimately an uplink to internet. The typical ZigBee transmission range is roughly 50 meters.

The ZigBee Alliance is providing a standardized base set of solutions for sensor and control systems. To allow vendors to supply the lowest possible cost devices the IEEE standard defines two types of devices: full function devices (FFD) and reduced function devices (RFD) [8]. An IEEE 802.15.4/ZigBee network requires at least one full function device as a network coordinator, but endpoint devices may be reduced functionality devices to reduce system cost.

The ZigBee Standard has evolved standardized sets of solutions, called 'layers' [8]. These layers facilitate the features that make ZigBee very attractive: low cost, easy implementation, reliable data transfer, short-range operations, very low power consumption and adequate security features.

ZigBee is very similar to Bluetooth but with some differences and advantages for home automation:

- A ZigBee network can consist of a maximum of 65535 nodes distributed in subnetworks of 255 nodes, compared to eight maximum of one subnet (Piconet) of Bluetooth.

- It has lower power consumption than Bluetooth. In exact terms, ZigBee has a consumption of 30mA in transmission mode and 3 μA at rest, against 40mA in transmission mode and 0.2mA at rest that Bluetooth has. This lower consumption is because the ZigBee system most of the time stays asleep while on a Bluetooth communication this is not possible and it is always transmitting and / or receiving.

- It has a speed of 250 kbps, whereas in Bluetooth is up to 3000 kbps, normally 1 Mbps.

- Because of the speed of these protocols, each one is more appropriate than the other for certain things. For example, while Bluetooth is used for applications such as mobile phones and home computers, the speed of the ZigBee becomes insufficient for these tasks, diverting it to applications such as home automation, dependent battery products, medical sensors, articles and toys, in which data transfer is lower.

Three main characteristics of ZigBee that have to be taken into account are the following:

1. Network and Application Support layer: The network layer has been designed to allow the network to spatially grow without requiring high power transmitters. The network layer also can handle large amounts of nodes with relatively low latencies. The APS sub-layer's responsibilities include maintenance of tables that enable matching between two devices and communication among them, and also discovery, the aspect that identifies

other devices that operate in the operating space of any device.

2. Physical layer: The IEEE 802.15.4 physical layer accommodates high levels of integration by using direct sequence to permit simplicity in the analog circuitry and enable cheaper implementations.

3. Media access control layer: The IEEE 802.15.4 media access control layer permits use of several topologies without introducing complexity and is meant to work with large numbers of devices.

4 Network Topologies

One of the great advantages of the IEEE 802.15.4 standard is the ability to create multiple alternative paths that will give robustness to any adversity through a mesh network. Although this type of topology is the most commonly used, there are others that are discussed below and can be seen in Figure 1.

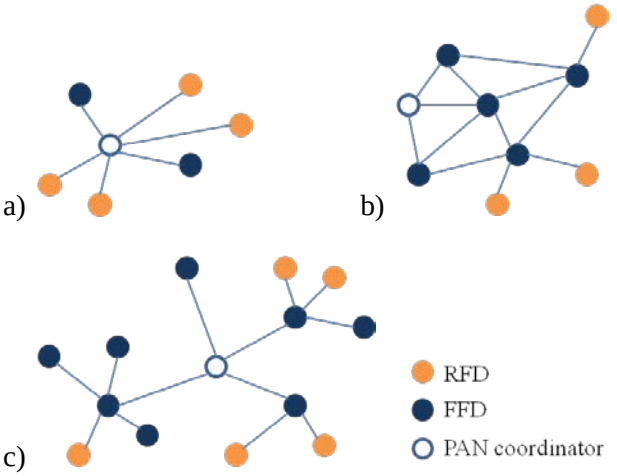

Fig. 1. Network topologies: a) star, b) mesh, c) cluster-tree.

Star: communications always go through the hub (central node), which acts as PAN (Personal Area Network) coordinator. Such networks are quite vulnerable because they depend on the proper functioning of the central node. Before the fall of the coordinator, it is essential to have in place a system for the network to be reconfigured again.

Mesh: As mentioned before, it is the preferred topology for the ZigBee technology. Multiple paths are created within the network that give robustness to the fall of one or more nodes. The grid structure can be complemented with small branches, hanging nodes with other or reduced functionality.

Cluster-tree: this topology encompassing the previous two topologies. A series of clusters (group of RFD –Reduced Function Device- nodes) are created where a FFD node (Full Function Device) adopts the role of coordinator of the cluster. Each cluster coordinator is responsible for communicating with all those nodes that has directly connected, creating a star arrangement. As a complement, if the vertices of the star are FFD, these can be linked with RFD, as it happens in the mesh topology.

5 CSMA/CA

The main function of the MAC layer is to manage access to the medium. The aim is that all nodes of the network share in an efficient and fair manner the transmission medium, in this case the radio channel [9].

The basis of the MAC protocol defined in the IEEE 802.15.4 is the CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) algorithm, that is, listen before talk (LBT). In the standard, two types of CSMA/CA are defined whose application depends on whether you opt for access control based on beacons or not:

1. Mode without beacon: based on unslotted CSMA/CA access.
2. Beacon-enabled mode: based on slotted CSMA/CA access.

5.1 Nonbeacon-enabled unslotted CSMA/CA network

In a network without beacons unslotted CSMA/CA is used. Each time a node wants to perform transmission of a packet, it must wait a random time, called backoff time, and during this time it does not hear the channel status. When this time has passed, the channel is heard. If the channel is free (there is no transmission in this moment), the node can transmit data. If the channel is busy, the node must wait another random period before trying to access the channel again. Figure 2 shows the flowchart of the medium access protocol.

In this process, some variables are involved:

- NB: counter of the number of times the backoff is executed to access the medium in each transmission attempt of a packet.
- BE: is the backoff exponent, which is related to the backoff time that the node waits before evaluating the state of the channel. Here it is assigned as the initial value macMinBE, where the value recommended in the IEEE 802.15.4 standard is 3.

- aMaxBE = Maximum permissible value for the variable BE. According to the standard default is 5. With this variable the maximum backoff time that the node waits before evaluating the channel is specified.
- macMaxCSMABackoffs = Maximum permissible value for the value of the NB variable, that is, the maximum number of transmission attempts. The standard defines the default value of 4.

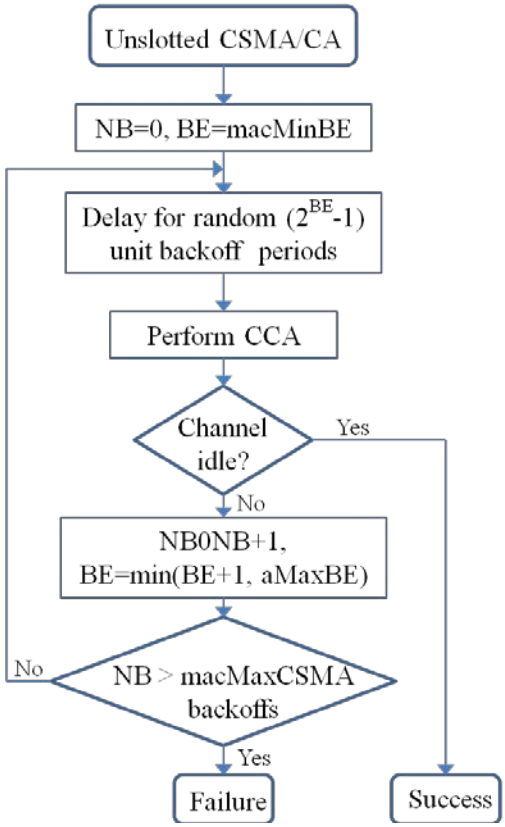

Fig. 2. Unslotted CSMA/CA algorithm

5.2 Beacon-enabled slotted CSMA/CA network

For networks with beacon mode activated, the channel access slotted CSMA/CA is used. In this case, the backoff periods are synchronized with the start of the transmission of a beacon.

The use of beacons adds a new level of functionality to the MAC layer of the network. Nodes can be in off mode and wake up only when they receive a beacon signal, listen to its direction and return to the sleep mode, thereby saving energy.

The beacon frames are important to keep all nodes synchronized without requiring nodes consume energy listening for long periods of time. In the Figure 3 the structure of a beacon frame is shown. The most important fields are in the MAC payload, which contains: superframe specification, GTS fields, pending address fields, and the beacon payload.

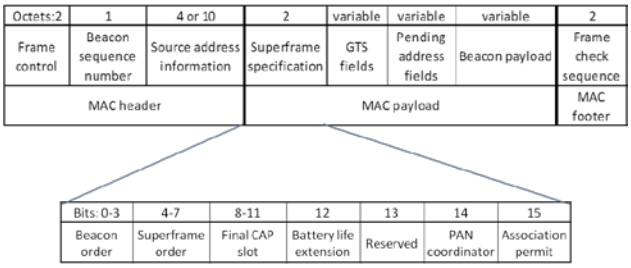

Fig. 3. Structure of the Beacon frame

The beacon-enabled mode is often used in networks of star topology, where a coordinator can create a superframe structure, defined by the regular transmission of beacons.

6 Conclusion

Most wireless nodes that operate with the IEEE 802.15.4 standard implements the unslotted CSMA/CA method as medium access (MAC) protocol. This MAC protocol offers high performance in environments with low traffic load and few nodes, providing good response in terms of transmission rate (throughput) and in terms of medium access delay (delay). However, its performance is seriously harmed when the number of nodes competing for the channel is high, or when the traffic load is high.

Furthermore, increasing the amount of wireless nodes in the market and the appearance of new multimedia services and applications has resulted in wireless networks become saturated with nodes that require higher transmission speeds.

Moreover, CSMA-based protocols are not commonly energy efficient, and Machine to Machine (M2M) applications, with a boom at present, require the operational and autonomous life of WSN is as long as possible in order to avoid the battery replacement cost. Therefore, it should be ideal to design new MAC protocols that provide good performance for any number of nodes and for high traffic loads, always offering energy efficiencies that ensure long lifetime in such networks.

There are currently numerous proposals for MAC protocols for ad hoc networks that improve the performance of CSMA/CA. DPCF MAC (Distributed Point Coordination Function) protocol is one of these proposals. It is a MAC protocol designed to work on wireless ad hoc environments.

The main design goal of this protocol is to increase the performance of these networks in terms of throughput and transmission delay.

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