Design of an autonomous decentralized MAC protocol for wireless sensor networks

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***Abstract*— In this document the design of a MAC protocol for wireless sensor networks is discussed. The autonomous decentralized TDMA based MAC protocol minimizes power consumption by efficiently implementing unicast/omnicast, scheduled rendezvous times and wakeup calls. The MAC protocol is an ongoing research topic in the European research project EYES.**

I. Introduction

ENERGY efficiency is believed to be the true bottleneck in current wireless sensor networks. The challenges to face in developing new technologies for sensor networks are the need for the nodes to be smart, self-configurable, capable of networking together, and the inherent poverty of resources within the network elements themselves. The main thrust of the work within the European research project EYES (IST-2001-34734; *http://eyes.eu.org*) is therefore directed towards the development of new architectural schemes, communications protocols and algorithms at multiple layers, taking into account the limited capabilities of the network nodes. In particular, schemes, which are able to work efficiently in the presence of limited energy, processing power and memory, will be developed. In this paper the design of a *medium access* (MAC) protocol for the EYES wireless sensor network will be discussed.

The EYES wireless sensor network will be organized in a hierarchical way by routing protocols, which makes data transport possible between network elements that are not within radio range of each other. This self-organizing hierarchical structure of the network allows to explore communication types in the network, what will be used to define the necessary MAC protocol functionality.

For the EYES project network nodes are designed to demonstrate the functionality of the designed adhoc networking protocols. Basically the network node design facilitates a physical layer to the air interface, which is a single radio channel at 868.35 MHz. The physical layer is capable of transporting bits at a rate of 115.2 kbps.

II. Goals

THE purpose of a wireless sensor networks is *physical environment* monitoring. Typical applications for such networks are: habitat monitoring, building climate control, burglary detection, early fire detection and many more. Each network node will be equipped with one or more sensors, which readings will be transported via other network nodes to a data sink, either after the data sink actively asked for the sensor data or when an event is detected by one of the nodes. The nodes will be spread with -possible- great redundancy and high spacial density in the area of interest. The topology of the wireless nodes can however change over time, due to for example mobility or failure of the nodes. This demands the communication protocols to be (virtually) stateless.

The type of applications makes that wireless sensor networks differ greatly from conventional networks like data or telecommunication networks. Wireless sensor networks are built of autonomous network nodes that each have limited processing power, memory and energy available. The networks have to operate in a self-organizing adhoc fashion, since none of the nodes is likely to be capable of delivering the resources to act as basestation or central manager.

In general two types of network nodes are recognized: nodes that mainly transmit their own sensor readings (*sensor nodes*) and nodes that mainly relay messages from other nodes (*relay nodes*). Sensor readings will flow from source node to sink node in the network via relay nodes. The type of a network node may change during the lifetime of the network. This type of hierarchical organization implies four types of communications (see Figure 1):

1) **Sensor node to sensor node communication:** This type of communication is used for local operations, like clustering of the network (hierarchy build up), route discovery and security authentication communication.
2) **Sensor node to relay node communication:** Sensor data is transmitted from sensor node to relay node. This type of communication is often unicast.
3) **Relay node to sensor node communication:** Requests for data and signaling messages (both often multicast) travel from relay node to sensor node.
4) **Relay node to relay node communication:** The relay nodes form the backbone of the wireless sensor network. Communication from relay to relay node will often be unicast.

The MAC protocol should support these communication types, while it minimizes the overhead necessary to set up connections. Moreover, it should allow for nodes to turn off their energy consuming transceiver as often as possible. Latency is in general less important in wireless sensor networks, although the support for mobile node communication requires a fast connection setup. These characteristic make a MAC protocol for wireless sensor networks fundamentally different

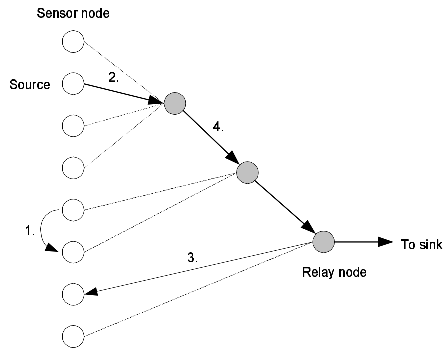

Fig. 1. Wireless sensor network hierarchy and communication types

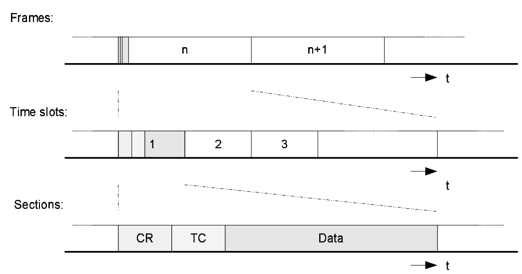

Fig. 2. The TDMA based MAC protocol

from MAC protocols for mobile adhoc networks.

These limitations and demands form a challenge for designing a power efficient communication protocol. Such a protocol has been designed and is still an ongoing research topic of the EYES project. In the next section the designed *energy efficient MAC protocol for sensor networks* (EMACS) will be discussed.

III. EMACS PROTOCOL

THE main task of the MAC protocol is to organize how the nodes in the wireless sensor network access the radio channel. The MAC protocol only deals with communications between nodes that are in radio range of each other. Higher layers should cope with the fact that the sink of the data is not always directly reachable.

In the EYES project we explore a TDMA based MAC scheme, since *code division multiple access* (CDMA) or *carrier sense multiple access* (CSMA) based protocols imply constant or very frequent listening to the radio channel. This listening to the channel consumes a large amount of energy, which is certainly not available in the network nodes. The TDMA EMACS protocol also eases the (local) synchronization between nodes.

Time is divided into so called frames and each frame is divided into timeslots (see Figure 2). Each timeslot can be owned by only one network node. This network node decides what communication should take place in its timeslot. Other nodes can ask for data or notify the availability of data for the owner of the timeslot in the *communication request* (CR) section.

The owner of the slot transmits its schedule for its data section and broadcasts a table in the *traffic control* (TC) section, which tells to which other TC sections the node is listening. After the TC section, the transmission of the actual data packet follows.

Since transmitting and receiving are both very power consuming operations, the network nodes should turn off their transceivers as often as possible. The EMACS protocol supports two sleep modes of the network nodes:

1) Standby mode: This sleep mode is used when at a certain time no transmissions are expected. The node releases its slot and starts periodically listening to a TC section of a frame to keep up with the network. When the node has to transmit some data (event driven sensor node), it can just fill up a CR section of another network node and agree on the data transmission, complete it and go back to sleep. It can actively be woken by other network nodes to participate in communication. Depending on the communication needs, it will start owning a timeslot.
2) Dormant mode: This sleep mode is agreed on higher layers. The sensor node goes to low power mode for an agreed amount of time. Then it wakes, synchronizes (rediscovers the network) and performs the communication. While in sleep mode the synchronization with the network will be lost and all communication with the node will be impossible. This sleep mode is especially useful to exploit the redundancy in the network.

Not every node in the network has to own a timeslot. It is clear that a node does not own a timeslot, when it is in one of the sleep modes, since being in a sleep mode is inherent to not transmitting a TC section every frame. But event driven nodes might also not redeem their right to own a timeslot. A draw back of not owning a timeslot is that the node will only be able to receive multicast messages and not messages directly addressed to the node. Transmitting data to nodes that own a timeslot is no problem. Other protocol layers in the network may invoke listening to/transmitting in an a priory agreed (and free or not owned) data section.

Before a node decides, that it does not want to own a timeslot, it should check that sufficient TC sections are transmitted by neighbors to keep the network connected and to maintain synchronization. The fact that nodes do not necessarily need to own a timeslot, eases the scalability of the network and reduces the power consumption of the nodes.

IV. CONCLUSION

THE proposed MAC protocol is designed to support communication types, which will often be used in wireless sensor networks. The protocol minimizes the utilization of the transceivers of the network nodes in order to save power. The data requests are made efficiently to reduce the bandwidth used in the network. Latency in the network is reduced by allowing transmissions in not owned or released data sections. The traffic control section can be deployed to make wake-up calls to sleeping nodes. In that case listening to one traffic control section per frame is assumed. Simulations and experiments must yet prove the concept of this autonomous decentralized MAC protocol design.