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Session 2 - Advances in Control Theory and Control Engineering
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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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A Survey of MAC Protocols in Wireless Sensor Networks

ABSTRACT

Wireless sensor networks are one of the most important technologies of the 21st century. A sensor network is a network of smallest computers, which are equipped with sensors and collaborate to perform a common task. A network of these devices has a wide range of potential applications including environmental monitoring, intelligent facility surveillance, medical systems and robotic exploration.

Many Medium Access Control (MAC) protocols have been specifically designed for wireless sensor networks where energy awareness is an essential design issue. In this paper we present a survey of the current MAC protocols for wireless sensor networks. We highlight the state of the art and compare between these protocols with respect to the sources of energy waste.

I. INTRODUCTION

A sensor network consists of many densely arranged sensor nodes. In order to make them universally applicable, they need to be small, cheap, durable and able to hold a long lifetime. Because today available batteries have a limited capacity, the energy reserves have to be handled economically. When the sensor node has consumed its charge completely, it is inactive and does not have the ability to execute its task any more.

[1] identifies the major sources for energy waste, namely collision, overhearing, sending and receiving of control messages, idle-listening and overemitting. Thus, a well-designed MAC protocol should reduce the effects of these sources and consequently reduce the waste of energy. Many MAC protocols are developed to overcome these sources. Therefore, it is necessary to evaluate these protocols regarding the sources for energy waste, presented above. The rest of this paper is organized as follows: Section (II) focuses on state of the art. Following this, section

(III) presents a comparison between these protocols with respect to the above presented sources for waste of energy. After that, we conclude with the main results and the future work in section (IV).

II. REVIEW OF MAC PROTOCOLS

As in all shared-medium networks, MAC is an important technique that ensures successful operation of the network. MAC protocols control the mutual access of the shared medium. Current MAC design for wireless sensor networks can roughly be divided into contention-based and schedule-based protocols. Contention-based protocols contest admittance to the medium. Only one node can gain exclusive access. Contrary, schedule-based protocols underlie a predefined order. The schedule defines when and how long every node can access the medium.

a) Contention-Based Protocols

Power Aware Multi Access Protocol with Signalling Ad-Hoc Networks (PAMAS) [2] based on the Medium Access with Collision Avoidance (MACA) [3] protocol with the addition of a separate signaling channel. The nodes switch their power off if they are not active, so overhearing is prevented.

Sensor Medium Access Control (S-MAC) [1] attempts to prevent idle-listening, overhearing and collisions. The nodes stick to a fixed schedule. All nodes wake up at predefined cycles and stay awake for a while. During this time synchronisation, sending and receiving of data proceeds.

Timeout Medium Access Control (T-MAC) [4] is an improvement of the S-MAC protocol with less idle-listening. This is achieved through an adaptively determined wake-up cycle. All data are transmitted in bursts of variable length and nodes sleep in between. More protocol-overhead is caused however because of the additional control messages.

Berkeley Medium Access Control (B-MAC) [5] is based on the simple Carrier-Sense-Multiple-Access with Collision Avoidance CSMA/CA protocol. The underlying network can be diagrammed as a spanning-tree, where the root is the base station and the leaves are the nodes. B-MAC achieves a higher throughput and better energy efficiency than S-MAC and T-MAC. A disadvantage is the idle-listening, because B-MAC always eavesdrops on the medium.

Pattern Medium Access Control (P-MAC) [6] determines the sleep / wake-up schedules for a node adaptively, it relies on its own traffic and that of the neighbours. P-MAC achieves more power savings at low working loads and higher throughput at heavier traffic loads.

Zebra Medium Access Control (Z-MAC) [7] combines the strengths of Time-Division-Multiple-Access (TDMA) and CSMA while offsetting their weaknesses. Like CSMA, Z-MAC achieves a high channel utilisation and a low-latency at low contention and like TDMA it achieves a high channel utilisation at a high contention. Z-MAC is robust to dynamic topology changes and time synchronisation failures that occur in sensor networks and more energy efficient than B-MAC and S-MAC.

Carrier Sense Multiple Access with Preamble-Sampling (CSMA-PS) [8], [9] is a protocol that combines classical CSMA with a preamble-sampling. CSMA-PS prevents protocol overhead. However, it wastes energy through the sending of a large preamble.

Wise Medium Access Control (WiseMAC) [10] depends on the preamble sampling technique to minimise the idle listening. WiseMAC minimises the length of the wake-up preamble by taking advantage of knowing the sensor nodes sampling schedules. Therefore, WiseMAC achieves a better power efficiency.

b) Schedule-Based Protocols

Low Energy Adaptive Clustering Hierarchy (LEACH) [11] is a clustering-based protocol that minimises the global energy usage by distributing the load to all nodes at different points in time. This results in reducing the energy dissipation and enhancing the system lifetime.

Event Driven Time Division Multiple Access (ED-TDMA) [12] is an energy efficient TDMA protocol for event-driven applications. ED-TDMA improves channel utility by changing the length of a TDMA frame according to the number of source nodes and saves energy by using a bitmap-assisted TDMA schedule.

Traffic adaptive Energy Efficient MAC (TEEMAC) [13] is a cluster-based MAC protocol where each cluster is dynamically formed based on the cluster head. It prevents collisions in data transmission, idle-listening, overhearing and unnecessary control overhead.

Application Medium Access Control (AppMAC) [14] is an application-aware and event-oriented MAC protocol. AppMAC combines the advantages of the contention-based and the schedule-based MAC protocols. AppMAC is able to support prioritised delivery of events, provide inter-event and intra-event fairness and improve channel utilisation while reducing energy consumption.

Self organizing Medium Access Control for Sensor-Networks (SMACS) [15] is a distributed MAC protocol. It enables a set of nodes to discover their neighbours and establish transmission / reception schedules for communicating with them.

Traffic Adaptive Medium Access (TRAMA) [16] is an energy-aware channel access protocol, which reduces energy consumption by ensuring that transmissions have no collisions and by allowing nodes to switch to a low-power mode whenever they are not transmitting or receiving data. TRAMA achieves high delivery guarantees and good energy efficiency.

Distributed Energy Aware Medium Access Control (DE-MAC) [17] is a TDMA based energy efficient MAC protocol. The protocol uses the TDMA technique together with periodic listening and sleeping to avoid the major sources of energy dissipation. DE-MAC achieves a significant gain in energy saving compared to other existing MAC protocols.

III. COMPARISON OF MAC PROTOCOLS

Contention-based protocols are preferable if the workload is not balanced. Busier nodes can get easier access to the medium. In the state of large workload schedule-based protocols are preferable, because they ensure an unproblematic transmission and a guaranteed throughput. The following tables present a comparative overview of different contention-based and schedule-based MAC protocols regarding the energy waste sources. A source of energy waste can be solved good, very good, bad or not solved in the discussed protocols.

Table1: Comparative overview of contention-based MAC protocols

	Idle-Listening	Collisions (Hidden-/ Exposed Terminals)	Overhearing	Protocol-overhead	Over-emitting
PAMAS	bad	very good/very good	very good	bad	very good
S-MAC	good	very good/very good	good	bad	very good
T-MAC	good	very good/very good	very good	bad	very good
B-MAC	bad	bad/bad	bad	very good	not solved
P-MAC	good	bad/bad	bad	bad	not solved
Z-MAC	bad	very good/very good	bad	bad	not solved
CSMA-PS	good	bad/bad	good	very good	not solved
WiseMAC	good	bad/bad	good	very good	not solved

Table 2: Comparative overview of schedule-based MAC protocols

	Idle-Listening	Collisions (Hidden-/ Exposed Terminals)	Overhearing	Protocol-overhead	Over-emitting
LEACH	very good	very good/very good	very good	bad	not solved
ED-TDMA	very good	very good/very good	very good	bad	not solved
TEEMAC	very good	very good/very good	very good	bad	not solved
AppMAC	good	good/good	very good	bad	not solved
SMACS	good	very good/very good	very good	bad	good
TRAMA	bad	bad/good	bad	bad	not solved
DE-MAC	bad	very good/very good	bad	bad	not solved

The table above shows that only LEACH, ED-TDMA and TEEMAC solve the idle-listening problem optimal. It's obvious that schedule-based protocols solve this problem better than contention-based protocols, because schedule-based protocols know when they are allowed to send and receive. In contrast contention-based protocols have to admittance to the medium. Collisions caused by hidden- and exposed stations are solved very well in all protocols expecting B-MAC, P-MAC, CSMA-PS, WiseMAC and TRAMA. Overhearing is more a problem of the contention-based than schedule-based protocols, because schedule-based protocols predefine who and when a node listens to the medium and when they shouldn't do. Regardless of those CSMA-PS and WiseMAC solve this problem in a good and PAMAS and T-MAC in a very good way respectively. With respect to protocol overhead they are completely different. Schedule-based protocols have more protocol overhead caused by organization and synchronization of the medium access while contention-based protocols don't need this and achieve a higher efficiency. The best protocols regarding protocol overhead are B-MAC, CSMA-PS and WiseMAC. With respect to the overemitting, only a few protocols attempt to solve this problem, namely PAMAS, S-MAC, T-MAC and SMACS.

IV. CONCLUSION

In this paper we have presented a survey of the well known MAC protocols and compared them to each other regarding the energy waste sources. Contention-based protocols are not underlying an explicit control. They react faster and better if the topology of the networks change often. The small or non-existent protocol overhead improves the scalability and efficiency. On the other hand, schedule-based protocols are subject to an explicit control because every node obtains a timeslot for sending and receiving data. Thus, organisation and synchronisation are the imperative of schedule-based protocols. The disadvantage of schedule-based protocols is that their adaptability and scalability are lower compared to contention-based protocols. The additional protocol overhead in schedule-based protocols improves collision avoidance. It produces however more energy waste. In the case of large workload, schedule based protocols ensure an unproblematic transmission and a guaranteed throughput.

According to section (III) we don't have found a winner under the MAC protocols. It is recommended to gather firstly the requirements of the application. Based on this information decisions for an appropriate MAC protocol can met. We see that it is not likely that a unified or "standard" MAC protocol for sensor networks will emerge.

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