Next Generation Mobile Networks and Ubiquitous Computing

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Chapter 16
MAC Protocols for Wireless Sensor Networks

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ABSTRACT

The chapter describes related work on medium access control protocols for wireless sensor nodes. We focus on scheduled and contention-based protocols that have been proposed by the research community during the last few years. In particular, we evaluate the potential to save energy of several representative protocols, namely LMAC, TEEM, and WiseMAC. This has been done by measurements of implementations in real sensor networks. The measurement results show that by sophisticated MAC protocol design we can significantly improve the energy-efficiency and increase the lifetime of a sensor node. Real-world measurements are important to determine power consumption parameters of sensor nodes.

INTRODUCTION

Wireless sensor networks (WSNs) use wireless network technologies for exchanging sensor data, signalling messages, management information etc. The wireless medium is shared by the various sensor nodes in a WSN. This requires a Medium Access Control (MAC) layer controlling the access to the wireless medium. Although many MAC layer protocols have been developed for both wired and wireless media, e.g., IEEE 802.11 Wireless Local Area Networks (WLAN), new MAC protocols are required for WSNs, because existing ones do not meet most requirements for sensor networks such as energy efficiency.

The most important task of a MAC protocol is to avoid collisions that occur when multiple nodes are trying to access the network simultaneously. By avoiding collisions valuable network resources are saved, the utilization of the wireless channel is

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improved, and the nodes save energy by avoiding useless transmissions. Other sources of energy waste are overhearing and receiving operations. Overhearing occurs when nodes receive packets destined to other nodes and can be dominant in scenarios with heavy load and high node density.

Since overhearing and receiving might not be much cheaper than transmitting, energy-efficient MAC protocols should avoid those operations and switch off the transceiver whenever possible. Other sources of energy waste are over-emitting, i.e. transmissions when receivers are not yet ready to receive as well as excessive control packet overhead.

The complexity of a sensor MAC protocol should be limited, because sensor nodes usually have limited computing and memory resources. Moreover, the MAC protocol should allow fair allocation of the wireless medium among all sensor nodes and aim at high throughput and low delay. In contrast to WLANs, a sensor MAC protocol must support not only small numbers of nodes but scale to hundreds or thousands of nodes depending on the required node density of a WSN by the application. The characteristics of a WSN in terms of size, density, and topology may change quickly requiring a sensor MAC protocol to be automatically adaptable.

The chapter gives an overview of related work in MAC protocols for WSNs including both scheduled and contention-based schemes. After describing the basic principles for MAC protocol operation in WSNs, we describe real-world experiments using implementations on real sensor nodes. The energy-efficiency in terms of sensor node lifetime will be investigated. We show that by proper MAC protocol design, significant energy savings are possible.

BACKGROUND

There are two basic classes of MAC protocols for WSNs: scheduled protocols and contention-based protocols. By combining the basic concepts, hybrid protocols can be designed.

Scheduled protocols are either based on polling or multiplexing. With polling a central controller polls other sensor nodes to detect whether they have pending transmissions. This avoids energy waste caused by collisions but introduces polling overhead and delays. In case of multiplexing, channels are pre-allocated based on time, frequency, or code multiplexing. Scheduling based approaches often form clusters with cluster controllers responsible for the channel allocation. Since only a certain number of channels can be allocated the scalability might be limited then.

Contention-based protocols allow sharing channels and allocating channels on-demand. The main problem is that contention can happen in case of dense networks and highly active sensor nodes. Moreover, collision avoidance is rather difficult to achieve in WSNs due to potentially hidden nodes.

SCHEDULED PROTOCOLS

Cluster-Based Approaches

Scheduled protocols based on cluster formation form clusters with a cluster head acting as base station. The cluster head allocates channels using time, frequency, and / or code multiplexing and assigns the channels to the sensor nodes. Typically, nodes can only communicate with a cluster head. Inter-cluster communication requires special mechanisms and (time, frequency, or code) channels. Cluster heads need to be interconnected to support data forwarding to / from sink, and since the distance among each other is rather high, higher power level for inter-cluster communication is needed.

In case of nodes joining or leaving the cluster, the frame length and the slot assignment need to be adapted. This might generate overhead. If the scheme does not adapt dynamically and uses static channel allocation, the achievable throughput is rather limited. An early example for a cluster-based protocol was Low Energy Adaptive Clustering Hierarchy (LEACH). Nodes organize themselves into clusters with rotating cluster heads as local base stations. Cluster members are only active during their schedule and might then transmit to the cluster head. The cluster head is permanently active, calculates TDMA schedules for other nodes, aggregates data, and forwards it to various nodes or via other cluster heads to the sink. The role of a cluster head is energy consuming and therefore rotated among nodes. A distributed protocol selects nodes as cluster head considering the energy level and the previous times a node served as cluster head.

Scheduled Protocols with Flat Network Organization

Several scheduled protocols avoid the overhead of building clusters and try to form a flat network. Three of those protocols, namely SMACS, TRAMA, and LMAC are described hereafter.

Self-Organizing MAC for Sensor Networks (SMACS) is an infrastructure building protocol that forms a flat topology. Nodes find each other on a fixed frequency and agree on a pair of time slots to send and receive data. Time slots are repeated periodically and nodes wake up for these time slots. The possibility of collisions is reduced by random selection of frequencies. The protocol requires time synchronization among the nodes.

Traffic Adaptive Medium Access Protocol (TRAMA) is a collision-free MAC protocol using a distributed election scheme to determine particular time slots. TRAMA distinguishes between contention-based random access slots used for signaling, and scheduled access periods used for collision-free data exchange.

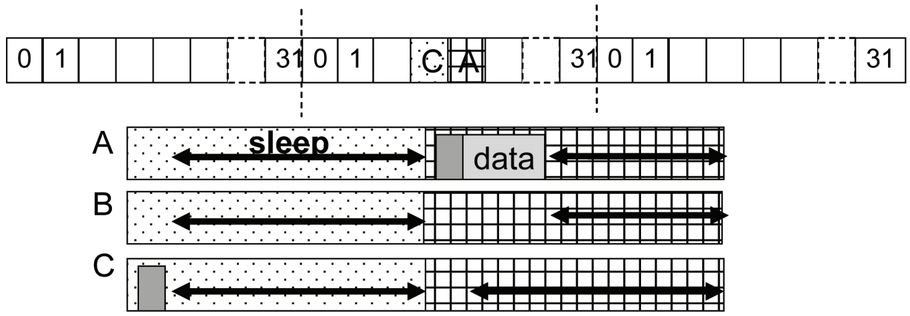
The TRAMA protocol assumes a time synchronization of sensor nodes. It consists of three protocol phases: Neighbor Protocol, Schedule Exchange Protocol, and Adaptive Election Algorithm. The Neighbor Protocol exchanges short control packets (keep-alive beacons) with 1-hop-neighborhood information during a random access period in order to obtain knowledge about the 2-hop-neighborhood around a node. In the Schedule Exchange Protocol, each node calculates a periodic schedule interval and winning intervals based on priority values: priority (u, t) = hash ($u \oplus t$), with t = time slot, u = a node in 2-hop-neighborhood. The schedules containing the set of receivers are announced periodically by schedule packets in the scheduled access period. All nodes switch to a sleep state whenever possible, i.e., when there is no traffic to be received or sent. The Adaptive Election Algorithm selects transmitters and receivers according to the information obtained from the two previous protocol phases.

Lightweight MAC (LMAC) is based on time multiplexing: Time is divided into time slots owned by various nodes using a distributed allocation algorithm. It divides a frame into 32 equal slots as shown in Figure 1. Each slot can be allocated by only one node. Furthermore, a node can own only one slot in a frame. Spatial reuse of time slots is possible. LMAC uses control messages to maintain the synchronization among nodes and to address the destination. The slot owner has exclusive transmission rights and can communicate collision-free. Figure 1 shows two slots in more detail. In the first slot, slot owner C has no data to send. It just sends a 12 byte SYNC message at the beginning of the slot and then turns off the radio to save energy. In the second case node A has data to transmit to B: The SYNC message and the data are sent in a single packet. All other nodes not involved in the communication shut down their radios after having received and analyzed the SYNC message.

CONTENTION-BASED PROTOCOLS

Contention-based protocols are characterized by having a common channel shared by all nodes.

Figure 1. LMAC



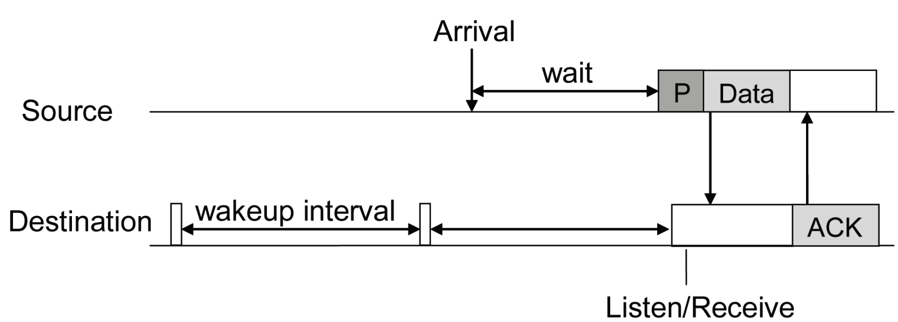
Resources are allocated on demand. This results in high flexibility in case of topology changes. Fine-grained time synchronization is not required. However, there is a high risk of inefficient energy usage due to idle listening and collisions.

Several protocols are based on entering a low duty cycle state and wake up the nodes when they are expected to receive a message. PicoRadio uses a special low-power control channel to indicate an upcoming transmission on a separate data channel. In other protocols the receiving node periodically wakes up to receive packets from sending nodes and falls into sleep again in case no transmissions occur. The transmitting nodes need to know the duty / sleep cycles of their neighbors, which may be achieved by synchronization of the wakeup periods as implemented in S-MAC. A disadvantage of periodic sleep is potentially high delays. An alternative is that the sender might try to wake up the receiver and indicate an upcoming transmission.

In STEM-B (STEM: Sparse Topology and Energy Management), the sending node sends a stream of beacon packets including the MAC addresses of sender and receiver in the paging channel to be answered by the receiving node. The receiver acknowledges the reception of the beacon and activates the data channel. By including the start time of the transmission in the beacon the receiving node can sleep until then. The STEM-T variant uses wakeup tones transmitted by the sender, which are not acknowledged by the receiver. All nodes in the neighborhood remain awake once they have overheard the wakeup tone and await the following transmission.

In WiseMAC, the sending node transmits a long preamble (Figure 2: P) with the length of the preamble larger than the sleep cycle. All nodes sample the medium using signal strength measurements with the same sampling period for activity, but sampling is not synchronized. A node that discovers a busy medium continues to listen,

Figure 2. WiseMAC



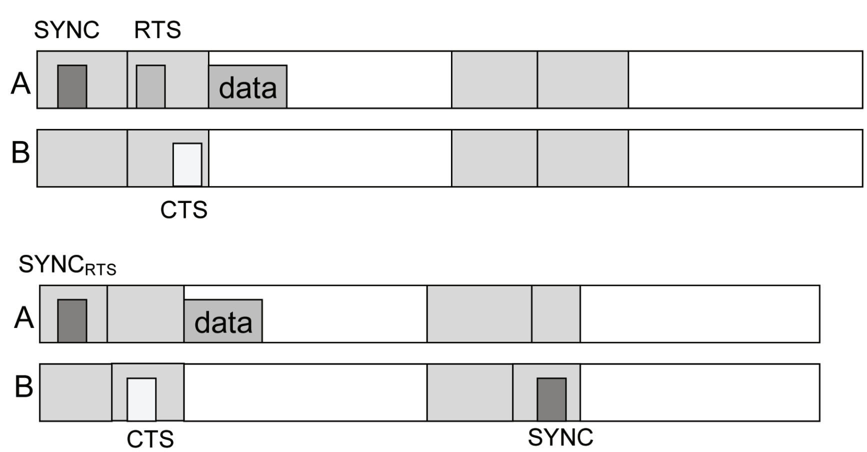
receives the packet, and becomes idle again. Long preambles are avoided by learning the sampling schedules of other nodes: Nodes piggy-back their sampling schedule in acknowledgement packets. The required preamble length Tp is: $Tp = \min(4 \cdot \theta \cdot L, Tw)$, with Tw = sampling period, θ = frequency tolerance, L= time of desired transmission.

Several other protocols based on periodic wakeup periods similar to STEM or WiseMAC have been designed. B-MAC employs an adaptive preamble sampling scheme to reduce duty cycle and minimize idle listening. CMAC uses an aggressive RTS transmission scheme to replace long preambles. Multiple RTS packets are separated by fixed short gaps, which allow receivers to send back CTS packets. X-MAC introduces a series of short preamble packets each containing target address information and thereby avoiding the overhearing problem of low power listening, saving energy on non-target receivers.

In S-MAC, each node has alternating sleep and listen states. In the sleep state, it turns off its radio and sets a timer to awake itself later, while in the listen state, it listens to see whether some other node wants to talk with it. S-MAC implements a so-called coordinated sleeping mechanism: Each node selects its own listen/sleep schedule. If the node receives a schedule from another node it follows that schedule, otherwise it selects its own schedule. The selected schedule is broadcast in a SYNC message. A node might receive a different schedule after announcing its own schedule. If the node does not have other neighbors it discards its schedule and takes over the new one. If the node shares schedules with other neighbors it adopts both (or more) schedules. The collision avoidance scheme of S-MAC is similar to IEEE 802.11 CSMA/CA using RTS/CTS message exchange (upper part of Figure 3).

The Traffic Aware Energy Efficient MAC (TEEM) protocol optimizes S-MAC by combining the SYNC and RTS messages into a single message to be sent when data is available for transmission. The listen period is shorter than in S-MAC and not fixed. If a node has data to send it tries to transmit the $SYNC_{RTS}$ for allocating the medium shortly after slot start (A in lower part of Figure 3). The receiver node addressed in $SYNC_{RTS}$ sends back a CTS message and waits for the incoming data packet. A successful transmission is approved by an ACK packet. If no node has data to send, one node will send a SYNC message in the second interval (B in lower part of Figure 3).

Figure 3. S-MAC and TEEM



HYBRID MAC PROTOCOLS

Hybrid MAC protocols combine TDMA scheduling and contention mechanisms by allowing contention in TDMA slots. Examples of such protocols are EMACs and Z-MAC. In EMACS each node owns a time slot. EMACS consists of three phases. In the first phase, any node is allowed to send requests for allocating a transmission slot. In the second phase, the time slot owner indicates which communication (his own or that one of the requesting node) will take place in the data phase. Finally, data is transmitted in the third phase.

Z-MAC operation is divided into a setup and a transmission control phase. In the setup phase neighbours discover themselves using ping messages and assign transmission slots using a distributed algorithm ensuring that no two nodes in a 2-hop-neighborhood get assigned to the same slot. This algorithm requires global time synchronization.

In the transmission control phase, each node is in either low or high contention level (LCL / HCL) dependent on received explicit contention notification messages sent based on local estimation of the contention level. If a node is in HCL state, only the slot owner and its 1-hop-neighbors are allowed to send, while in LCL state all nodes are allowed to send in any slot. In general, slot owners have higher priority by using a smaller contention window for back-off.

IEEE 802.15.4 / ZIGBEE

The IEEE 802.15.4 standard describes a physical and MAC layer for sensor networks and is also used for the Zigbee protocol architecture. There are two kinds of devices:

- A full-function device (FFD) is capable of operating as coordinator and implementing the complete IEEE 802.15.4 protocol set.
- A reduced-function device (RFD) is operating with a minimal implementation of the IEEE 802.15.4 protocol set

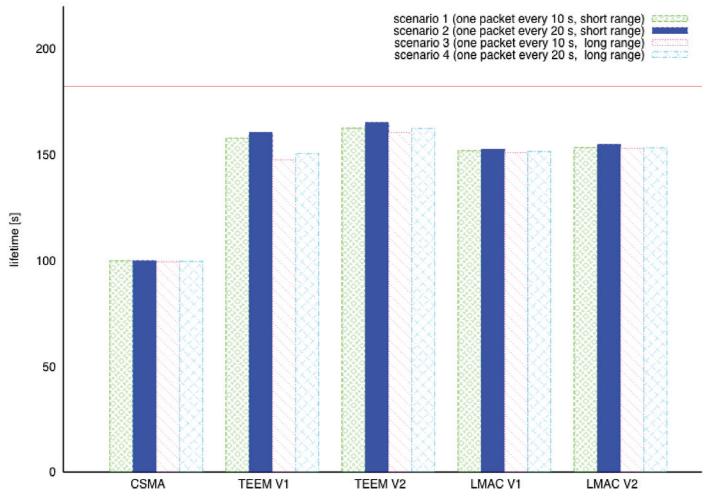
A coordinator node is a FFD that is configured to provide synchronization services through the transmission of beacons. The coordinator defines an optional super-frame structure with 16 equally sized slots. Beacons synchronize devices and define the start of a super-frame. A super-frame may have an active and inactive period. The coordinator may enter low power mode during inactive period. The active period is further divided into a contention access period and a contention free period. The coordinator may allocate up to 7 guaranteed time slots (GTS) in the contention-free period. A slotted CSMA/CA protocol is used for the contention access period.

EVALUATION OF SELECTED SENSOR MAC PROTOCOLS

This section describes the evaluation of selected MAC protocols for WSNs by measuring the lifetime in real-world test-beds. The implementation in real test-beds is important to determine power consumption parameters accurately. Power consumption parameters from manufacturer data sheets are typically not sufficiently accurate.

In order to investigate how much energy can be saved with sophisticated sensor MAC protocols, we implemented the LMAC and the TEEM protocol on Embedded Sensor Boards (ESBs). In addition to the original protocol versions , we tried to improve the performance of both protocols. For TEEM we allowed more than one packet per slot, and implemented an acknowledgement vector to confirm the reception of multiple packets. In the improved LMAC version, packet markers in the SYNC message helped to identify packet boundaries more easily. Moreover, SYNC messages are protected by CRC checksums. Both

Figure 4. Lifetime Measurements of TEEM and LMAC



improved protocol versions are denoted as versions 2 hereafter.

Several measurement scenarios consisting of node chains have been used for the evaluation of the two protocols: In a short range scenario, all the five nodes hear each other, but a packet from node 5 is sent via intermediate nodes to the sink. In a long range scenario, the five sensor nodes are distributed in a building and can only communicate with their respective neighbor nodes. Different packet rates (1/10 s and 1/20 s) are used. In all scenarios, the node closest to the sink is equipped with a special capacitor with well-defined, but very limited energy. The lifetime was measured by determining the time when the RS-232 interface of the node has been shutdown when using a 1Farad gold cap capacitor instead of batteries.

The lifetime measurements depicted in Figure 4 show that the different TEEM and LMAC versions significantly increase the lifetime of node 1 compared to the default ScatterWeb CSMA MAC protocol implemented in the ESB nodes. Both improved versions slightly improve the lifetime of the original versions. TEEM performed slightly better than LMAC in terms of both network lifetime, but much less packet errors could be detected for TEEM. LMAC was rather difficult to implement on the available hardware due to difficulties to achieve good time synchronization between the nodes.

The lifetime evaluation in the WiseMAC experiments have been slightly changed compared to the measurements on TEEM and LMAC. We switched off the RS232 interface and determined the lifetime until the supply voltage of the capacitor has fallen below 3 V. We measured the lifetime of WiseMAC in a chain scenario consisting of six nodes with the parameters depicted in Table 1.

Table 1. Measurement Parameters for WiseMAC Evaluation

Basic Interval Duration T	500 ms
Awake Ratio	1%
Retries	3
Minimum Preamble	5 ms
Medium Reservation Preamble	uniform [0,6] ms
Baud Rate	19’200 bps
Bit Rate	9’600 bps
MAC Header	104 bit
Payload	96 bit
Packet Queue Length	20

Figure 5 depicts the lifetime of the fifth ESB node as a function of the traffic rate r when being charged with the initial amount of energy. As the node's energy consumption increases with increasing traffic along the chain, a more or less linear decrease of the node's lifetime can be observed. The lower curve in Figure 9 displays the lifetime of a node using ScatterWeb CSMA. ScatterWeb CSMA keeps the transceiver constantly in the receive state, applying no energy-saving scheme such as periodic switching between sleep and active states. We can see that the WiseMAC implementation achieves a lifetime that is more than twice than for the Scatterweb CSMA implementation. This is a much higher factor than what we achieved for LMAC and TEEM and indicates that WiseMAC is very energy-efficient.

FUTURE TRENDS

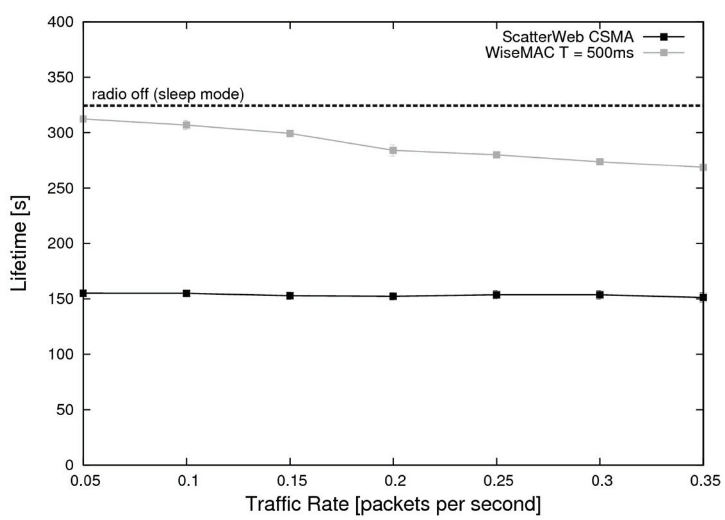
Future work will integrate such MAC level protocols with higher-level protocols such as routing and transport protocols. Such integration is called cross-layer design.

Future work might also include protocols for even smaller sensor nodes such as required for body area networks. Nodes must be small and light to be carried conveniently by users. Energy-efficiency might become even more important. However, transmission ranges will be in the order of a few meters only.

CONCLUSION

This chapter described the state of the art in MAC protocols for WSNs. Those protocols can be classified into scheduled and contention-based protocols. The implementation of several representatives of these classes showed that sophisticated protocols significantly increase the lifetime of a sensor node. Due to the lower implementation complexity as well as better lifetime and packet error results, the contention-based protocol has some advantages over the scheduled protocol. Moreover, we discovered that determining power consumption parameters must be determined by real-world implementations, because data sheets from hardware manufacturers are typically not accurate enough and can lead to wrong results when applied in simulation experiments.

Figure 5. Lifetime Measurements of WiseMAC



REFERENCES

Braun, T., Voigt, T., & Dunkels, A. (2007). TCP Support for Sensor Networks. *4th IEEE/IFIP Conference on Wireless On demand Network Systems and Services.* Obergurgl, Austria.

Buettner, M., Yee, G., Anderson, E., & Han, R. (2006). X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks. *4th international Conference on Embedded Networked Sensor Systems (SenSys)* (pp. 307-320). Boulder: ACM.

Demirkol, A. (2006, April). MAC Protocols for Wireless Sensor Networks. *IEEE Communications Magazine*, 115. doi:10.1109/MCOM.2006.1632658

Enz. (August 2004). WiseNET: An Ultralow-Power Wireless Sensor Network Solution. *IEEE Computer*, 62-70.

Feeney, L. M., & Nilsson, M. (2001). *Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment*. IEEE INFOCOM.

Heinzelman, W., Chandrakasan, A., & Balakrishnan, H. (October 2002). An Application Specific Protocol Architecture for Wireless Microsensor Networks. *IEEE Transactions on Wireless Communications*.

Hoesel, V., & Havinga. (2004). A Lightweight Medium Access Protocol (LMAC) for Wireless Sensor Networks: Reducing Preamble Transmissions and Transceiver State Switches. *INSS.*

Hoesel, V., & Havinga. (2004). A TDMA-based MAC Protocol for WSNs. *ACM SenSys.*

Hurni, P., & Braun, T. (2008). Evaluation of WiseMAC on Sensor Nodes. *10th IFIP International Conference on Mobile and Wireless Communications Networks (MWCN2008).* Toulouse: IFIP.

Hurni, P., Braun, T., & Feeney, L. M. (2006). Simulation and Evaluation of Unsynchronized Power Saving Mechanisms in Wireless Sensor Networks. *4th International Conference on Wired/Wireless Internet Communications* (LNCS 3970, pp. 311-324).

IEEE. (2003). *Specific requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs).* 802.15.4 IEEE Standard for Information technology - Telecommunications and information exchange between systems — Local and metropolitan area networks.

Ilyas, M., & Mahgoub, I. (2005). *Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems*. CRC Press.

Karl, H., & Willig, A. (2006). *Protocols and Architectures for Wireless Sensor Networks*. Wiley.

Liu, S., Fan, K.-W., & Sinha, P. (2007). CMAC: An Energy Efficient MAC Layer Protocol Using Convergent Packet Forwarding for Wireless Sensor Networks. *4th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)* (pp. 11-20). IEEE.

Polastre, J., Hill, J., & Culler, D. (2004). Versatile low power media access for wireless sensor networks. *2nd international Conference on Embedded Networked Sensor Systems (SenSys)* (pp. 95-107). Baltimore.

Raghavendra, C., Sivalingam, K., & Znati, T. (2004). *Wireless Sensor Networks*. Kluwer. doi:10.1007/b117506

Rhee, Warrier, Aia, & Min. (2005). Z-MAC: A Hybrid MAC for Wireless Sensor Networks. *ACM Sensys.*

Schiller, J., Liers, A., Ritter, H., Winter, R., & Voigt, T. (2005). ScatterWeb - Low Power Sensor Nodes and Energy Aware Routing. *Hawaii International Conference On System Sciences (HICSS 2005).*

Schurgers, T. G. (2002, January). Optimizing Sensor Networks in the Energy-Latency-Density Design Space. *IEEE Transactions on Mobile Computing*.

Staub, T., Bernoulli, T., Anwander, M., Wälchli, M., & Braun, T. (2006). Experimental Lifetime Evaluation for MAC Protocols on Real Sensor Hardware. *ACM Workshop on Real-World Wireless Sensor Networks (REALWSN'06)* (pp. 25-29). Uppsala, Sweden: ACM Press.

Suh, C., & Ko, Y.-B. (2005). A traffic aware, energy efficient MAC protocol for wireless sensor networks. *International Symposium on Circuits and Systems (ISCAS'05).*

Ye, W., Heideman, J., & Estrin, D. (June 2004). Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks. *IEEE/ACM Transactions on Networking*, 496.

Ye, W., & Heidemann, J. (2003). *Medium Access Control in Wireless Sensor Networks* (USC/ISI Technical Report ISI-TR-580).

Zhong, S. G. (2001). An Ultra-Low Power and Distributed Access Protocol For Broadband Wireless Sensor Networks.

KEY TERMS AND DEFINITIONS

Cluster Formation: Scheduled protocols need often a node that controls channel assignment. In this case, a cluster of nodes is formed and a cluster controller is responsible for channel assignment within the cluster. It also takes over the task of communicating with other clusters.

Contention-Based MAC Protocols: Contention based MAC protocols do typically not reserve channels for individual nodes, but try to resolve collisions by distributed protocol mechanisms, typically based on listening to the wireless medium and transmitting only after silence has been observed on the channel.

Hybrid MAC Protocols: Hybrid MAC protocol apply principles of both contention-based and scheduled MAC protocols.

Lifetime of a Sensor Node: Energy of a sensor node is typically provided by batteries and is a very scarce resource. If the supply voltage falls below a certain threshold, the sensor node is not any more able to work properly and its lifetime can be considered as expired.

Medium Access Control (MAC): The MAC layer is a sub-layer of the data link layer and aims to ensure that nodes access a shared medium in way that they not interfere with each other and avoid collisions.

Scheduled MAC Protocols: Collision avoidance in MAC protocols can be addressed by providing dedicated channels to individual sensor nodes, e.g. by assigning time slots in the case of time multiplexing

Wireless Sensor Network (WSN): a set of sensor nodes that can communicate with each other via wireless communication and possibly using multi-hop communication, i.e., packets can be relayed by sensor nodes