Chapter 13: QoS-aware MAC protocols for wireless sensor networks- A survey

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Outline

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Introduction

- What is common in these emerging application domains is that performance and quality of service (QoS) assurances are becoming crucial as opposed to the best-effort performance in traditional monitoring applications.
- The term QoS is widely used in the area of all kinds of networks but still there is no consensus on its exact meaning.
- Summarize different types of QoS approaches and discuss which can be applied to WSNs. Additionally, we mention the QoS perspectives, namely application-specific QoS and network-specific QoS, and discuss the requirements of different types of applications.
- Discuss the QoS mechanisms that can be applied in the context of WSNs. We then continue explaining the details of existing QoS-aware MAC protocols for WSNs including their QoS metrics, parameters, mechanisms and present an extensive comparison of them.

Background and QoS perspectives

- QoS provisioning and service differentiation in traditional networks.
- QoS perspectives in WSNs.
- QoS support at MAC layer.

QoS provisioning and service differentiation in traditional networks.

- QoS is the ability of a network to satisfy the certain requirements of the user or application. There are two main types of QoS provision defined in wired and wireless networks:
  - **Hard QoS :** should be provided deterministic QoS guarantees, such as strict bounds on packet delays, bandwidth or packet losses.
  - **Soft QoS :**has tight QoS requirements but the temporal violations on QoS provisioning can be tolerated to a certain extent.
- Service differentiation is the widely adopted scheme in both wired and wireless networks to provide hard/soft QoS guarantees.

QoS perspectives in WSNs.

- classified the QoS perspectives in WSNs into two categories as Application-specific and Network-specific
  - **Application-specific perspective :** Application-specific perspective Application-specific perspective focuses on the quality of the application itself. QoS is again assured by fulfilling the requirements imposed by the application such as lifetime , coverage , deployment, quality of the sensing, camera resolution, number of active sensors.
  - **Network-specific perspective :** Network-specific perspective provides service quality during delivery of the data by the communication network. From this perspective, network resources are utilized efficiently in each layer of the communication protocol stack to fulfill the requirements imposed by the carried data, such as latency, packet loss, reliability.

QoS support at MAC layer

- All the communication protocol stack entities is essential for QoS provisioning, MAC layer possesses a particular importance among them since it rules the sharing of the medium and all other upper layer protocols are bound to that.
- QoS support in the network or transport layers cannot be provided without the assumption of a MAC protocol which solves the problems of medium sharing and supports reliable communication.
- MAC layer handles the additional challenges of the WSNs such as severe energy constraints by duty cycling and unpredictable environmental conditions by methods such as retransmissions or transmission power control.
- MAC layer plays a key role for QoS provisioning and dominates the performance of the QoS support.

QoS challenges in WSNs

- **Resource constraints:**
  - WSNs lack of bandwidth, memory, energy and processing capability.
  - Limited energy is the most crucial one since in many scenarios it is impossible or impractical to replace or recharge batteries of the sensor nodes.
- **Node deployment :** Deployment of the sensor nodes may be either deterministic or random.
  - In deterministic deployment, sensor nodes are placed by hand and routing can be performed through pre-scheduled paths.
  - In a random deployment, sensor nodes are deployed randomly and organize themselves in an ad hoc manner.
- **Unbalanced traffic:**
  - Unbalanced traffic flows from sensor nodes to sink nodes or cluster heads are commonly observed in WSNs.
  - Event-driven applications mostly cause sporadic changes in the traffic pattern in case of event detection. smart routing protocols may share the traffic load between different routes, MAC protocol still has to accommodate unbalanced and bursty traffic.

QoS challenges in WSNs(cont.)

- **Topology changes:**
  - Node mobility, link failures, node malfunctioning, energy depletion or natural events like flood or fire can cause topology changes.
  - Most of the link layer or MAC layer protocols employ sleep-listen schedules and turn the radio of the sensor nodes off temporarily for energy saving. This kind of power management mechanisms also cause frequent topology changes.
  - Inevitably, dynamic nature of the WSN topology introduces an extra challenge for QoS support.
- **Data redundancy:**
  - WSNs comprise a large amount of tiny sensor nodes and hence, observed event or phenomena can be detected by several sensor nodes. Although this redundancy helps reliable data transfer, it also causes unnecessary data delivery in the network which consequently yields to congestion.
  - Data aggregation/fusion mechanisms may decrease the redundancy but also may introduce additional delay and complexity in he system. Therefore, effective QoS mechanisms are needed to cope with the data redundancy.

QoS challenges in WSNs(cont.)

- **Multiple traffic types:**
  - Sensor nodes which have the capability of sensing or observing various phenomena can generate different types of traffic.
  - Applications requiring existence of multiple traffic classes add extra challenging issues to QoS support since requirements of traffic classes differ from each other.
- **Real-time traffic:**
  - In some critical applications like natural disaster monitoring or security surveillance, gathered data is valid only for a limited time frame and has to be delivered before its deadline. This type of critical real-time data must be handled by adequate QoS mechanisms.
- **Scalability:**
  - Most of the WSNs are composed of hundreds or thousands of sensor nodes.
  - As the area of interest or requirements for the quality of observation increase , more sensor nodes need to be deployed.
  - Designed QoS mechanism must scale well with highly dense or large scale networks

QoS requirements, metrics and parameters

- QoS requirements
- Qos metrics and parameters

QoS requirements

- QoS requirements of different applications differ from each other.
- Therefore, application requirements are also important for network-specific QoS. Rather than investigating the QoS requirements of every application in WSNs, it is a better approach to focus on the data delivery models that are used in different applications and map the requirements of these data collection models to a set of QoS metrics.
- There are three basic data delivery models:
  1. Continuous model.
  2. Query-driven model.
  3. Event-driven model.

QoS requirements

- **Event-driven model:**
  - In this model, sensor nodes report data only if an event of interest occurs.
  - The success of the network depends on the efficient detection and notification of the event that is of interest to the user.
  - This is bound to quality and accuracy of the observation related to the observed phenomena with reliable and fast delivery of the information about the detected event.
  - Also creation of highly redundant and bursty traffic by sensors affected by the same event is very likely to be observed in event driven applications.
- **Continuous model :**
  - In this model, sensor nodes transmit the collected data at periodic intervals and can be considered as the basic model for traditional monitoring applications based on data collection.
  - The data rates can be usually low and to save energy the radios can be turned on only during data transmissions if scalar data is collected.
  - For periodically collected non real-time data, latency and packet losses are tolerable. Surveillance or reconnaissance can be an example of this class.

QoS requirements (Cont.)

- **Query-driven model:** is very similar to the event-driven model with an exception:
  - Data is pushed to the sink without any demand by the sensor nodes in event-driven model while data is requested by the sink and pushed by the sensor nodes in the query-driven model.
  - Hence, contrary to the one-way traffic of event-driven model, two-way traffic comes into scene which consists of requests of the sink and replies of the sensor nodes.
  - Both requests and replies must be delivered quickly and reliably for achieving higher performance in query-driven applications.
- **Hybrid :**
  - If the mentioned data delivery models coexist in the same network, carried traffic must be classified and requirements of these traffic classes must be satisfied.
  - A surveillance application that sends both periodic temperature and event-triggered video data is an example of the hybrid model.

Qos metrics and parameters

- **Minimizing medium access delay :** It is certain that in order to minimize the end-to-end delay from sensor sources to the sink node, the performance of routing layer should also be taken into account.
- **Minimizing collisions :** Collisions, and consequently retransmissions, directly impact the overall networking metrics.
  - Collisions can be prevented by careful carrier sensing methods, such as adapting contention window according to the traffic requirements, considering the contention-based protocols.
  - Similarly, adapting the number of time slots, frequencies according to network requirements can prevent collisions in the case of contention-free protocols.
- **Maximizing reliability:**
  - Related with minimizing the collisions, MAC layer can also contribute to reliability assurance.
  - Acknowledgement mechanisms can be used to identify the packet losses and accordingly retransmissions can be performed in time to fix the problems.

Qos metrics and parameters

- **Minimizing energy consumption:** Energy efficiency is still the most important requirement in WSNs due to the battery-limited operation of sensor devices.
  - MAC layer can contribute to energy efficiency by minimizing collisions and retransmissions and more importantly can tune the duty cycle of the sensor devices according to the network dynamics.
- **Minimizing interference and maximizing concurrency (parallel transmissions):** Since wireless medium is a shared medium.
  - Interference causes packet loses and hence affect the throughput, delay and energy efficiency of the network.
  - Maximizing concurrency while limiting the impact of interference on parallel transmissions can contribute to these metrics.
  - MAC layer can achieve minimal interference and maximum concurrency by tuning the related parameters, such as contention windowing, timing, transmission power, operating channel.

Qos metrics and parameters

- **Maximizing adaptivity to changes** : WSNs are characterized by their dynamic behavior.
  - Nodes may deplete their battery and disconnect from the network, new nodes may be added to the network, links between nodes may change in time due to environmental conditions or topological changes, traffic conditions may change according to the monitored phenomena.

Important MAC layer QoS metrics for application classes.

QoS metric	Event driven	Query driven	Cont.	Hybrid
Medium access delay	✓	✓		✓
Collision rate			✓	✓
Reliability	✓	✓		✓
Energy consumption	✓	✓	✓	✓
Interference/concurrency			✓	✓
Adaptivity	✓	✓		✓

QoS mechanisms in WSNs at MAC layer

- **Adaptation and learning：**
  - Sensor nodes may try to learn the characteristics of the network during their operation and take the necessary adaptive precautions against changing conditions beforehand rather than responding afterwards.
- **Power control :**
  - It increases the concurrent communications by decreasing interference, hence improves the channel utilization. However, dynamic nature of the wireless links makes the implementation of power control mechanism a challenging task.
- **Data suppression and aggregation**
  - Data suppression and aggregation mechanisms try to minimize radio communication by reducing the traffic load of the network, hence provides energy saving.
  - Data suppression and aggregation techniques are strictly application dependent and similar to error control, they can be implemented in any layer of the protocol stack.
  - As the router nodes wait for other packets to aggregate, the latency of the packets being aggregated increases.

QoS mechanisms in WSNs at MAC layer

- **Error control**：Aim of the error control mechanisms is to reduce energy consumption while providing reliable and fast delivery of the sensory data.
  - **Automatic Repeat Request (ARQ)** can be used to provide guaranteed hard QoS by persistent retransmissions until the data is successfully delivered.(If latency, drop ratio and energy consumption per successfully transmitted packet can grow to unacceptable levels, especially for delay-bounded real time traffic in case of frequent retransmissions.)
  - **Forward Error Correction (FEC)** is to prevent retransmission of the entire data packet in case of partial errors by including some redundancy in it.This redundancy is then used to recover failures caused by wireless channel at the receiver side. (FEC mechanism has certain shortcomings, they can be alleviated by changing the strength of the FEC code based on the current channel conditions.)
  - **Hybrid ARQ** takes advantage of both ARQ and FEC mechanisms. (Initially, data packets are weakly coded or not coded at all by the sender. If the received packet is in error and cannot be recovered, receiver sends a negative acknowledgement to the sender. The sender than recodes the packet with a more powerful FEC code and resends the packet. This cycle continues until the packet is successfully delivered.)

QoS mechanisms in WSNs at MAC layer

- **Clustering**
  - It is very hard to provide global synchronization in WSNs considering the large deployments and the number of sensor nodes.
  - This challenge has led the development of clustering mechanisms to simplify the synchronization and coordination by grouping set of neighboring sensor nodes.
  - Clustering provides significant energy saving by improving inter-node connectivity and facilitating data aggregation, hence can be used to provide QoS support in terms of energy consumption and reliability.

QoS mechanisms in WSNs at MAC layer

- **Priority assignment**
  - **Dynamic priority assignment:**
    1. **Remaining hop count:** In a multi hop WSN, remaining number of hops to the destination of the packet can be used as a parameter for packet prioritization.
    2. **Traversed hop count:** The number of traversed hops can be used for prioritization since losing, dropping or missing the deadline of a packet which has traversed more hops will be waste of more network resources than the one which has traversed less hops.
    3. **Packet deadline :** The closer a packet is to miss its deadline, the higher priority it should have, since the packet will be useless after its deadline.
    4. **Remaining energy :** Increasing the priority of the packets as the remaining energy of the generating or relaying sensor node decreases, extends the lifetime of the sensor node by preventing the energy waste caused by idle listening.
    5. **Traffic load :** Forwarding loads of the sensor nodes can change depending on their position or role in the network. Giving higher priority to the sensor nodes that have relatively heavier forwarding load can decrease the packet dropping ratio caused by buffer overflow.

QoS mechanisms in WSNs at MAC layer

- **Priority assignment (cont.)**
  - **Static priority assignment:**
    1. **Traffic class:** Packets can be prioritized based on the type of traffic like real-time, non-real-time, best effort.
    2. **Source type :** QoS mechanism can specify set or sets of sensor nodes or sinks which generate more important data than others and assign all network entities a priority. Consequently, the node which generates the packet also gives the priority of itself to its packets, i.e. packet inherits the priority of its creator.
    3. **Data delivery model :** Priority of the packets can be selected based on the associated data delivery model.
  - **Hybrid priority assignment :** Priority of the packets can be determined in a hybrid manner by considering both static and dynamic decision criteria. Moreover, by giving certain weights to these criteria, importance degree of the packet can be calculated more precisely and mapped to a priority level.

QoS mechanisms in WSNs at MAC layer

- **Differentiation methods**
  - **Changing Contention Window (CW) size :** Contention based medium access schemes necessitate a contention period between the sensor nodes that attempt to send data concurrently, in order not to interfere with each other's transmission. Following the contention period, one of these sensor nodes wins the contention and qualifies to reserve the communication channel and sends its data.
  - **Changing contention slot selection probability:** In random access MAC schemes, contender nodes normally select a contention slot in a random fashion. However, employing non-uniform probability distributions for contention slot selection makes significant difference .
  - **Changing inter-frame space (IFS) duration:** In contention based medium access schemes, IFS is defined as the amount of time that sensor nodes stay quiet just before the contention or back off period.
  - **Changing back off exponent :** Although IFS and contention periods are utilized to overcome collisions in contention based medium access schemes, it is impossible to totally eliminate collisions because more than one sensor nodes may set their timers to the same time or select the same contention slot.

QoS mechanisms in WSNs at MAC layer

- **Differentiation methods**
  - **Transmission slot scheduling :** Reservation-based medium access schemes divide the time into small portions called slot.
  - **Changing active time:** MAC protocols employing sleep listen schedule for energy saving can set the active time of the sensor nodes according to their priority level.
  - **Changing adaptation speeds:** Changing adaptation speeds: Some protocols dynamically adapt themselves to the current network conditions by changing some parameters like CW size or back off exponent during operation of the sensor node. Using different coefficients for the adaptation of parameters can control the speed of convergence to local optimums, hence can provide service differentiation .
  - **Changing error correction strength :** MAC protocols utilizing error control mechanisms to provide QoS support can accommodate service differentiation by changing either persistency of retransmissions or strength of the error control codes .
  - **Changing DoA:** DoA needs accumulation of packets at the buffer of the router node which causes longer delays. On the other hand, lower DoA decreases the quality of redundancy elimination and increases the energy consumption. Therefore, employing variable DoA for each traffic class can be a technique for service differentiation in terms of delivery latency .

QoS-aware MAC protocols for WSNs

- Protocols with differentiated services
- Application-specific protocols
- Comparisons

Protocols with differentiated services

- **PSIFT** is a QoS-aware MAC protocol designed for event-driven applications and it is based on the SIFT protocol , which exploits the spatial correlation property of WSNs.
  - PSIFT is a Carrier Sense Multiple Access (CSMA)-based MAC protocol and provides traffic differentiation by varying the inter frame space (IFS) and contention window (CW) size for each traffic class, as shown in Fig.. Traffic classes are prioritized in a dynamic manner based on the traversed number of hops, i.e. the higher number of hops traversed, the higher level of priority that a packet has.
  - Advantages and disadvantages: Although PSIFT might be a sensible choice for event-driven applications, it is nearly impossible to be used in any other type of applications.
  - Report suppression mechanism decreases the traffic load in the network and leads to mostly idle sensor nodes. This advantage of the PSIFT must be utilized to decrease the energy consumption of the network by integrating a sort of sleep listen schedule.

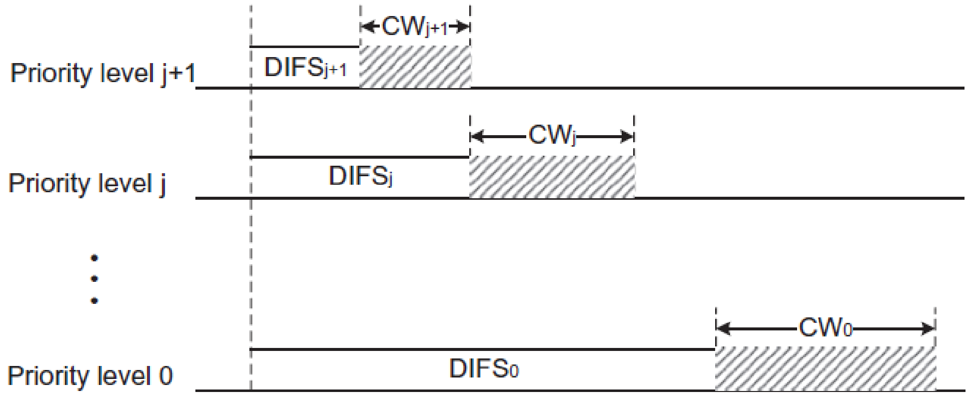

Fig. 2. Service differentiation in PSIFT

Protocols with differentiated services

- **Q-MAC** utilizes intra-node scheduling to select the next serviced packet from different priority queues and inter-node scheduling to coordinate the medium access among multiple neighboring nodes
  - Advantages and disadvantages: Dynamic priority assignment provides robustness against changing conditions of the sensor network. However, calculation of the transmission urgency of a node is relatively complex. Integration of the increasing geometric probability for CW selecting may decrease the collision rate but also may result in higher latencies.

Protocols with differentiated services

- **PQ-MAC** aims to use advantageous features of both contention based and schedule based approaches and uses a hybrid scheme for medium sharing.
  - Global clock synchronization, neighbor discovery and accordingly slot assignment are done during the setup phase and followed by the transmission phase where the real data delivery takes place.
  - Advantages and disadvantages: The neighborhood of the sensor nodes, relay nodes or cluster heads may change frequently because of the dynamic nature of the WSNs. Therefore, accuracy of the slot assignment performed once at the beginning of the setup phase will be obsolete during the transmission period gradually. This improves the channel utilization and reduces the probability of collision significantly at the cost of tight clock synchronization.

Protocols with differentiated services

- **SASW-CR** is a slotted Aloha based MAC protocol for Ultra-wideband (UWB) sensor networks with QoS support.
  - Authors assume all nodes in the network are classified as high or low priority depending on the traffic they generate and service differentiation between them is achieved by using disjoint contention windows. A cooperative retransmission technique based on overhearing is also utilized to provide fast and reliable data delivery.
  - Each sensor node maintains two queues; namely data queue which stores the created data packets by the sensor node itself and overhearing queue which stores overheard packets during transmission belonging to neighboring sensor nodes.
  - Advantages and disadvantages: Although cooperative retransmission improves the MAC layer performance, each node must acquire acknowledgements broadcast by the sink node in order to eliminate unnecessary copies of overheard packets. Moreover, maintaining such a mechanism requires continuously active sensor nodes which results in high energy consumption.

Protocols with differentiated services

- **Saxena et al. MAC** aims to offer QoS for multimedia transmission over WSNs and to conserve energy without violating QoS-constraints.
  - Energy conservation is achieved by employing adaptive duty cycles according to the dominantly processed traffic in the sensor node. Hence, each sensor node follows its own sleep-listen schedule.
  - Advantages and disadvantages : Although highly dynamic operation of the protocol adapts well to the changing network conditions, it introduces a significant overhead and complexity. Additionally, idle listening and early sleeping problems most likely to occur since there is no local or global synchronization between sensor nodes. The protocol causes lower-priority packets to suffer from high latencies.
- **PR-MAC** gives different priorities for each type of event monitored by the sensor nodes and provides service differentiation among these events by varying both CW size and IFS for each of them.
  - The sender node transmits a short pulse to reserve the medium rather than using RTS-CTS exchange. Hence, collisions can only occur during transmission of the burst pulse among nodes of equal priority.
  - PR-MAC reserves the medium without RTS-CTS message exchange, and hence reduces the control overhead. However, it may face some problems to support variable size packet delivery since RTS packets includes the medium reservation duration.

Protocols with differentiated services

- **RL-MAC** is a QoS-aware reinforcement learning (RL) based MAC protocol and uses a CSMA scheme.
  - As a local observation, the number of successfully transmitted and received packets during the active time period is recorded to be used in the duty cycle adaptation with proportional load of the queues.
  - Advantages and disadvantages: Relatively complex RL based algorithm adapts the network conditions very well but it might not be feasible to be implemented on energy and processing power constrained sensor nodes.
- **QoMOR -aware** MAC protocol using Optimal Retransmission (QoMOR) is designed for the intra-vehicular sensor networks and assumes the sensor nodes have only the transmission capability.
  - Advantages and disadvantages: Reduction of receiver hardware decreases the cost of the sensor nodes considerably. One way transmission of the data and absence of coordination makes QoMOR very lightweight and simple solution for one-hop sensor networks.

Protocols with differentiated services

- **IEEE 802.15.3/802.15.4 and extensions**
  - **IEEE 802.15.3 standard** is to develop an ad hoc MAC layer for high data rate wireless personal area networks (WPANs) and a physical layer that can reach up to 20Mbps.The standard is geared towards handling voice, images and file transfers and it has an operational transmission range of approximately 10 m. Basically, the standard is specified for higher data rate scenarios and does not address the requirement of energy efficiency or other QoS requirements in WSNs.
  - **The IEEE 802.15.4 standard** is adopted by WSNs, interactive toys, smart badges, remote controls and home automation operating on license-free ISM bands. is intended as a specification for low-cost, low-powered networks with no critical concerns about throughput and latency. Therefore, QoS issues have not been the main concern in the original specification.
- **I-MAC** uses a hybrid TDMA/CSMA scheme for medium access and basically introduces a prioritization mechanism for Z-MAC.
  - Authors propose a scheduling algorithm called DNIB [73] and time slots are assigned to each sensor node based on this algorithm. Owner of the time slot has guaranteed access in that particular slot and this guarantee is provided by employing Arbitration Inter frame Space (AIFS) for non-owner sensor nodes.
  - Advantages and disadvantages: Authors developed a novel scheduling algorithm and achieved better utilization than of Z-MAC. However, possessing up-to-date neighbor information and slot schedule in highly dynamic sensor networks is a major challenge.

Protocols with differentiated services

- **Diff-MAC** aims to increase the utilization of the channel with effective service differentiation mechanisms while providing fair and fast delivery of the data.
  - Advantages : Fast adaptivity to changing network conditions and network-wide fairness of Diff- MAC make it a very strong candidate for multimedia sensor applications.
  - Disadvantages : Monitoring network statistics and dynamic adaptation are complex and overwhelming operations. Additionally, although lack of sleep-listen synchronization between neighboring sensor nodes improves the protocol scalability, it also increases the packet latencies caused by early sleeping.
- **EQ-MAC** is designed to provide QoS support for cluster based single-hop sensor networks by service differentiation and uses a hybrid medium access scheme.
  - Advantages and disadvantages: Probability of collisions and energy consumption are reduced by using contention based medium access for short periodic control messages and by scheduled medium access for long data packets.

Application-specific protocols

- **EQoSA** is a hybrid MAC protocol which is designed to provide QoS support especially for video and image transmission over sensor networks.
  - Advantages and disadvantages: EQoSA suffers from the traditional time synchronization problem of TDMA based schemes and only has the ability to accommodate bursty traffic load rather than a proper service differentiation mechanism. Moreover, it needs more powerful cluster heads within the sensor network to perform and announce the slot assignment.

- **Suriyachai et al. MACs** provides QoS support by giving deterministic bounds for node-to-node delay and reliability, hence can be a suitable candidate for applications requiring absolute delay and reliability assurance.
  - Advantages and disadvantages: Since each node synchronizes its clock with its parent node, synchronization errors can propagate increasingly. Also, each node must be aware of its position in the data gathering tree for slot assignment and duty cycling. Therefore, Suriyachai et al. MAC does not scale well for large networks.

QoS-aware MAC protocols for WSNs

- **Comparisons**
  - The table also presents comparisons of the discussed algorithms in two groups, namely protocols with differentiated services and application-specific protocols.
  - Performance of the MAC protocols for WSNs are highly application dependent. Therefore, we need to evaluate the performance of all surveyed protocols under the same application or simulation environment, which is quite hard to be done, in order to make accurate quantitative comparisons in terms of communication delay, delay jitter, throughput, energy efficiency, lifetime, etc.

Table 2
Comparison of QoS-aware WSN MAC protocols in the literature.

Protocol	Type	Service diff.	Priority assignment	Traffic adaptivity	Synch.	Energy awareness	Complexity	Scalability
PSIFT [53]	CSMA	✓	Dynamic	No	None	No	Low	Good
Saxena et al. [49]	CSMA	✓	Static	Yes	None	Yes	High	Good
PR-MAC [52]	CSMA	✓	Static	No	None	No	Low	Weak
RL-MAC [50]	CSMA	✓	Static	Yes	None	Yes	High	Good
Q-MAC [54]	CSMA	✓	Hybrid	No	None	Yes	Moderate	Good
PQ-MAC [57]	TDMA/CSMA	✓	Static	No	Locally	Yes	High	Weak
QoMOR [60]	ALOHA	✓	Static	No	None	No	Low	Weak
802.15.4 ext. [58]	CSMA	✓	Static	No	None	No	Moderate	Good
I-MAC [56]	TDMA/CSMA	✓	Dynamic	Yes	Locally	No	Moderate	Weak
Diff-MAC [74]	CSMA	✓	Hybrid	Yes	None	Yes	High	Good
SASW-CR [51]	ALOHA	✓	Static	No	None	No	Moderate	Weak
EQ-MAC [75]	TDMA/CSMA	✓	Static	Yes	Locally	Yes	High	Weak
EQoSA [76]	TDMA/CDMA	–	–	Yes	Locally	Yes	Moderate	Weak
Suriyachai et al. [78]	TDMA	–	–	No	Network wide	Yes	Moderate	Weak

QoS-aware MAC protocols for WSNs

- **Comparisons(cont.)**
  - We observe two main trends in QoS-aware MAC protocols for WSNs: protocols that follow differentiated services approach and protocols that provide application specific QoS support.
  - Protocols that provide service differentiation can further be classified as the protocols that provide static differentiation, protocols with dynamic differentiation where dynamic parameters are tuned at the MAC layer.

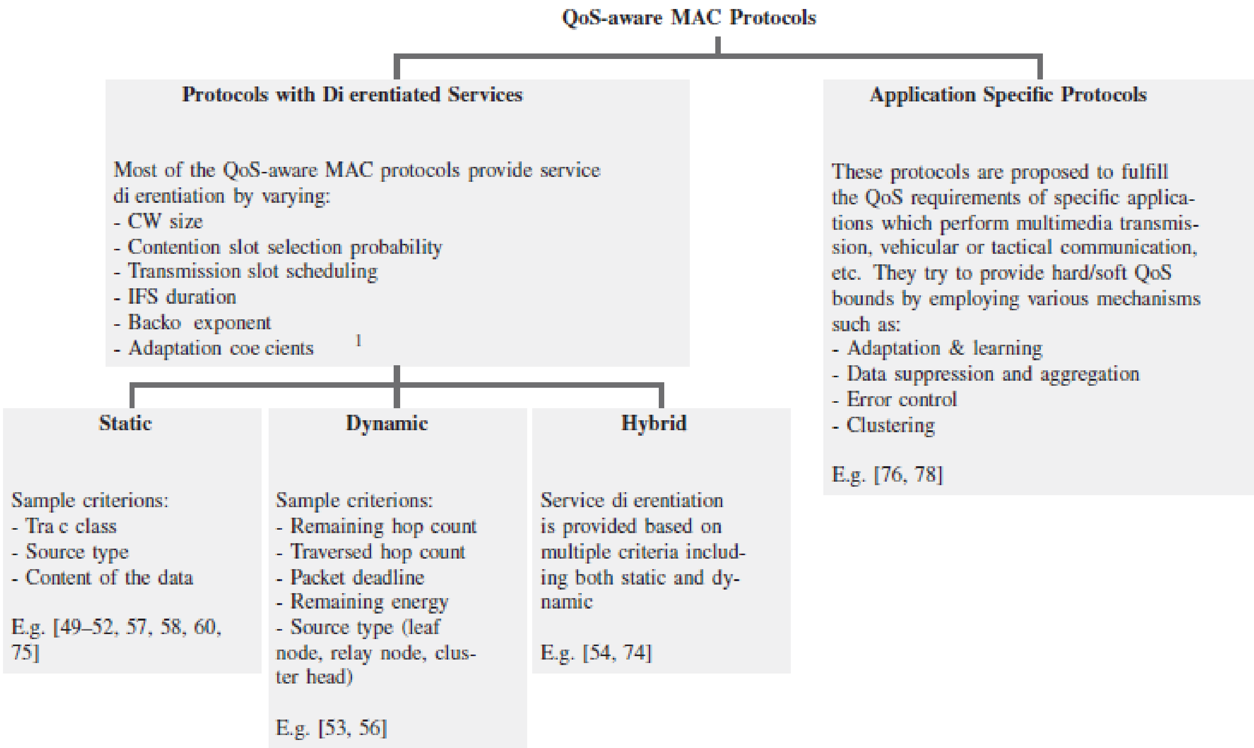

Fig. 6. Classification of QoS-aware MAC protocols.

Properties of a well-designed QoS-aware MAC protocol

- The designed QoS-aware MAC protocol must be scalable since WSNs can be composed of excessive number of sensor nodes or deployed to large are For this reason, distributed and unscheduled MAC protocols seem to be more suitable to autonomous and ad hoc nature of the WSNs. As
- Node mobility, environmental effects or node malfunctioning may result in highly dynamic network topologies which makes the adaptive MAC layer requirement a must.
- Service differentiation mechanisms can be counted as the most effective way of sharing network resources, especially in resource constrained WSNs.
- Developers must keep in mind that QoS support in WSNs are highly application-specific. Hence, the performance of the QoS-aware MAC protocols extremely depends on the requirements of the application.

Conclusions

- According to this survey, we observe that instead of providing deterministic QoS guarantees, majority of the protocols follow a service differentiation approach by classifying data packets according to their type and packets of different types are treated according to their requirements by tuning the associated network parameters at the MAC layer.
- There are also a few application-specific protocols and protocols that provide indirect QoS support by differentiating the MAC parameters according to the network conditions.
- Design tradeoffs and open research issues are also investigated to point out the further possible investigations in the field of QoS provisioning in WSNs at MAC layer to contribute to the further research efforts in the field of WSNs.

Homework #13:

1. What are the challenge of QOS in the wireless network?
2. Describe Classification of QoS-aware MAC protocols.