# Reasons for priority-based Medium Access in Wireless Sensor Networks

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***Abstract*—The trend towards heterogeneous wireless sensor networks and cyber-physical systems results in new challenges for the communications protocols. The co-existence of these networks can result in an unacceptable performance decrease if they interfere with each other or share the same radio channel. Especially, in the latter case, priority-based medium access with Quality of Service (QoS) guarantees is required to assure that the different networks can accomplish their tasks. In this paper, we introduce different use cases and priority strategies. Furthermore, the advantages and drawbacks of current solutions are discussed.**

## I. Introduction

Priority-based medium access mechanisms become more and more important in the area of Wireless Sensor Networks (WSN) since networks do not only focus on a single application. The latest generation of WSNs usually performs various tasks at the same time, e.g. sensing of temperature, pressure or stress and strain. The sensor nodes either periodically transmit the sensed data or only start to communicate as soon as a certain threshold is exceeded. The priority of the generated data then depends on the corresponding application, the type of the sensed data and the sensed value. Consider a sensor network for Structural Health Monitoring where nodes periodically sense temperature and stress strain of critical components.

The sensed data can be transmitted with the same priority to a data sink as long as no threshold is exceeded. However, in the case that a fire is detected due to high temperature increase, the data packets containing temperature values should have a higher priority in order to track the fire. On the other hand, the stress and strain measurements will be of higher importance during an earthquake to estimate the lifetime of critical components or to initiate an alert. Some events, like a fire, are often limited to certain area and are thus only detected by a small number of nodes. These nodes should have a higher medium access priority in case of an emergency to minimize the time to initiate countermeasures. In addition, it is very common that nodes start to sense the corresponding phenomena more frequently to provide better knowledge about the event. This behavior results in a higher data rate which should be taken into account by the Medium Access Control (MAC) protocol. Event-driven data traffic [1] represents a serious issue in dense sensor networks where nodes also transmit periodic data traffic since the low power transceivers are very limited in their sensing capabilities [2]. Due to the shared medium, transmissions of nodes with less important periodic data traffic affect the performance of the high priority traffic. Therefore, it is important that the MAC protocol supports priority-based medium access to mitigate or overcome this issue of varying traffic load and priority.

This paper is organized as follows. An introduction to different use cases and priority strategies is given in Section II. In Section III, the advantages and drawbacks of two different solutions are discussed. Finally, we conclude in Section IV.

## II. Use Cases and Priority Strategies

QoS requirements are defined by a WSNs' target application. In Section I, we briefly introduced several application examples with different QoS requirements. A more general view on the requirements of several application scenarios can lead to basic strategies for prioritized medium access. We will discuss the general requirements of these classes in Section II-A, and discuss the basic medium priority access strategies that emerge from these requirements. Afterwards, we present QoS strategies that can be used to implement concrete priority access schemas for several applications in Section II-B.

### A. Medium Access Priority Classes

Priority based medium access requirements and strategies can be divided into two groups. The first group of application requirements can be seen in an application that requires *Static Medium Access Priority*. Such static requirements can be found in simple WSNs where many nodes are deployed that fulfill different tasks which are assigned different priorities. Task priorities can be assigned during node configuration before the network is deployed. One advantage of static priorities is that the behavior of the network is highly predictable: The node with the highest priority is able to access the medium immediately in case of a free radio channel, or immediately after the current transmission if the channel is busy.

The second group of applications contain all scenarios where a priority scheme is not known at configuration time, but depends on run time parameters. Such applications require a *Dynamic Medium Access Priority* scheme to fulfill their QoS requirements. Dynamic priority strategies are based on changing conditions, which emerge at run time. Such conditions can be the battery energy level, the waiting queue length, data rate, buffer level, and distance to the root or number of neighbors. Dynamic medium access typically results in a more complex network behavior. Estimating parameters for minimum, maximum, or average latencies or other performance parameters requires a detailed understanding of the encoded priority metric. Basically, dynamic access strategies can be used for two purposes: They can be employed to balance the network load equally on all available nodes, or shift it to nodes which are capable of handling higher loads. Or they can be used to guarantee fair medium access. Metrics which consider the traffic load and buffer level of nodes are of particular interest in WSNs since nodes are very limited in terms of energy and memory.

### *B. QoS Strategies*

Several strategies can be used to implement the previously introduced dynamic and static access priority classes. Unreliable links and varying channel conditions over time present challenges [3] that are not considered by traditional QoS-support mechanism like IntServ [4] and DiffServ [5]. Therefore, such traditional schemes can hardly be applied in the context of WSNs. This is especially true since WSN nodes have severe resource constraints such as limitations of computational power, memory and bandwidth. Due to these additional constraints impact the requirements for the strategies: They should be as simple as possible while meeting the QoS requirements of the target application. In the following, we introduce different strategies for priority-based medium access that can significantly improve the network performance. One, or several, of these strategies must be chosen before a WSN is deployed by a WSN administrator. We therefore discuss the pre-requisites for each strategy and highlight possible application scenarios which can benefit from these strategies.

*1) Topology-aware access strategy:* Some WSNs consist of several types of nodes: few powerful nodes with little constraints form a backbone. A lot smaller and constraint devices are grouped around these backbone nodes, competing for media access with these non-constrained devices. If a high priority is assigned to the backbone nodes, the medium access delay for these nodes is reduced. Hence, the delivery ratio is increased since the number of nodes with high access priority is very small. Furthermore, such a strategy gives the backbone nodes control of the medium access which improves the support for data aggregation mechanisms.

*2) Network-aware access strategy:* The self-organizing capability of WSNs have made the technology an attractive solution for several monitoring tasks: nodes can be randomly placed in a field or in areas which are or become hardly accessible, e.g. due to radioactive contamination. This however can come with a drawback: some scenarios do not allow for the replacement or removal of network nodes. For example, asymmetric links or partitioning of the network can make reprogramming or remote shut down of the nodes impossible. If a new network should be deployed on top of another network, or an existing network should be upgrade, this can become a problem due to the shared characteristic of the medium. This can limit the performance of later deployed networks which operate on the same radio channel, especially if nodes frequently transmit data until their batteries are drained. A priority-based medium access strategy which employs network IDs can mitigate the problem of co-existing networks. Network IDs can be used to represent the medium access priority of the WSNs: a higher ID corresponds to a higher access priority and vice versa. One the one hand, this strategy allows the deployment of a new high priority WSNs on top of an already deployed sensor network, which could not be removed or shut down. On the other hand, a new low priority WSN can be placed within the area of another sensor network without having a large impact on the performance of the already deployed network.

*3) Traffic-aware access strategy:* More and more sensor networks perform different tasks at the same time. Traffic-awareness within the MAC protocol is required if the tasks have different priorities. Assume a WSN in which nodes generate traffic with different priorities, e.g. the stress and strain measurements of a structural health monitoring application, which has high QoS requirements, and temperature measurements which can be transmitted as best effort traffic. An operator may therefore assign different traffic priorities for these two application types, thus improving performance metrics for the high-priority application traffic.

*4) Service-aware access strategy:* Virtualization of networks and services has become very popular in recent years, with the first implementations already available [6]. These techniques allow several users to access nodes and their sensors in a shared manner. Resource allocation for each user on the device has been the focus of extensive research. To the best of our knowledge, medium access priorities in conjunction with virtualization has not been an issue. Assigning priority classes for medium access for virtualized applications, allows fair media sharing between the virtualized applications.

*5) Distance-aware access strategy:* Measured data is typically transmitted from a large number of data sources to a small number of data sinks. This sinks can process or forward the data into a non-constrained environment. Such networks are often organized in a tree structure [7], which allows taking advantage from data aggregation and data processing mechanisms. Medium access in such a setup can be a major performance factor due to the increasing traffic load towards the sinks. A priority-based medium access procedure that adopts the access priority depending on the distance to the sink can support the data aggregation mechanisms or decrease the energy consumption of the sensing nodes. If nodes that are closer to the sink have a higher priority, the delay in event-based WSNs can be reduced since the node which is triggered by the event and is closest to the sink has the highest priority. Thus, it can immediately access the medium to transmit its data, which reduces the event detection time. On the other hand, assigning a higher priority to nodes that are further away can reduce the overall energy consumption: Nodes that are furthest away from the sink can transmit their data immediately and turn off their transceiver at the end of the transmission. Furthermore, it improves the potential of data aggregation due to the fact that all children of a node in the tree have a higher medium access priority than their parent. As a result, the children can transmit their data to the parent before the parent gains access to the medium in order to forward the data.

*6) Energy-aware access strategy:* Most wireless sensor nodes have very limited power supplies. Therefore, designers of communication protocols try to minimize the energy consumption as much as possible while meeting the requirements of the target application. Routing protocols, which take energy consumption into account, typically try not to forward traffic via nodes that have only a small amount of energy left. Such mechanisms have proven to balance the traffic load and to prolong the lifetime of WSNs. However, the access to the medium can become costly as well in terms of energy if a node requires several attempts to gain its access. For this reason, nodes which run low on power should have a high medium access priority in order to reduce the average number of access attempts.

*7) Buffer-aware access strategy:* Limited amount of memory of wireless sensor nodes becomes a serious problem if the nodes should be able to support the Internet Protocol (IP). Especially, fragmentation of data packets and forwarding of packets leads to high memory consumption. It has to be kept in mind that most sensor nodes, e.g. TelosB, T-Mote and Mica, only have 8KB or 10KB of ram which makes buffering of multiple large packets almost impossible. Furthermore, event-driven traffic patterns in WSNs can lead to temporary high network load. Routing protocols with load-balancing support have been designed to mitigate the impact of this issue in multi-hop networks. However, a buffer-aware MAC protocol can further improve the performance by taking the length of the waiting queue into account: Nodes that have more packets stored in their waiting queue should have a higher medium access priority. As a consequence, the maximum waiting queue length and the percentage of dropped packets due to buffer overflows could be decreased. This strategy also improves the fairness in dense single hop networks provided that the nodes generate traffic at the same data rate.

*8) Data-rate aware strategy:* The latest generation of routing protocols for WSNs, e.g. the Collection Tree Protocol (CTP) [7], apply adaptive mechanisms to cope with frequent topology changes. In general, these protocols increase their beacon transmission rate if they detect changes in their neighborhood. Topology changes usually result from interference or mobility of the nodes. The latter may lead to frequent topology changes which significantly increase the routing overhead. In dense networks, the routing overhead can even result in temporary congestion of the network. Temporary congestion can also be caused by applications which generate event-driven traffic, e.g. intruder detection or structural health monitoring applications. For these kinds of applications, it is important to receive information from all nodes which have detected the event to gain more precise information and to minimize false positives. The priority of the medium access should depend on the transmission rate of the nodes. A fair medium access can be achieved if a higher transmission rate results in a lower access priority and vice versa. Thus, nodes which rarely transmit traffic have a high probability of gaining access to the medium immediately. However, nodes that frequently transmit traffic can utilize the whole bandwidth as long as no other nodes need access to the medium.

## III. SOLUTIONS

The range of applications for WSNs steadily increases and so does the demand for flexible and adaptive communication protocols [8] which suit the requirements of the target application. Current solutions mainly focus on Time Division Multiple Access (TDMA) based protocols since they provide a good performance in scenarios where the topology is stable and traffic patterns are known in advance. However, even in these cases TDMA based solutions have a high complexity and suffer from limited hardware resources such as computational power and precise oscillators. Thus, additional synchronization mechanisms are required to compensate the clock drift. As a result, large gaps between consecutive slots should be applied to avoid collisions due to asynchronous time clocks. The impact that gaps have on the overall throughput depends on the duration of the time slots and the duration of the gaps. Nonetheless, the gaps can only be shortened to some extend even if perfect synchronization is assumed since low power transceivers require a significant period of time to switch between receive and transmit mode and vice versa. Otherwise, a node cannot listen to its subsequent slot if it has transmitted in its own time slot. In addition, a node cannot use the full duration of its own time slot if it was listening to the previous time slot.

Due to these drawbacks of TDMA based protocols, we decided to follow a different approach based on the transmission of preambles [10], [11] which is less complex. The protocol uses the preamble to resolve the contention on the one hand and provide priority based medium access [12] on the other hand. The basic idea of the protocol is to transmit a preamble of variable length to indicate that access to the medium is desired. After the transmission of the preamble, the node switches its transceiver back to receive mode and senses the medium. If it senses a busy medium after the transmission of its preamble, it assumes that another node has sent a longer preamble and therefore has a higher access priority. Thus, only the node with longest preamble senses an idle medium and starts its data transmission. A collision can only occur if two or more nodes start their preamble transmission at the same time and choose the same preamble length. A detailed description of the collision probability of the BPS-MAC protocol with different configuration is given in [11]. Instead of using a single preamble, the protocol can be configured such that is uses multiple sequential preambles. In this case, the first preamble corresponds to the access priority whereas the subsequent preambles are used to resolve possible contention. This approach is very flexible and does not require additional mechanisms, e.g. synchronization or complex algorithms for slot allocation. However, the preamble transmission reduces the maximum throughput. In addition, the transmission of preambles increases the interference which has to be taken into account. Therefore, the protocol should be configured with respect to the maximum expected traffic load.

## IV. Conclusion

Priority-based medium access represents an interesting field of research since the latest trends in WSNs show that there is clear demand on this functionality. The mechanisms make sensor networks more flexible such that they can respond more quickly to events or to fulfil different sensing tasks at the same time. Existing TDMA based solution already provide this functionality to some extent. However, they achieve this functionality by the price of high complexity. In addition, they are less flexible due to the fact that the slot duration cannot be changed dynamically to meet the requirements of the target application. Preamble-based solutions for priority-based medium access represent a new fresh approach which is more flexible compared to their TDMA based counterparts. In our future work, we will focus on the performance comparison preamble-based and TDMA-based solutions for multi-hop WSNs with QoS requirements.

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