A Deterministic Wireless Sensor Network for Time-Critical Applications

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Abstract. Looking toward the deployment of WSNs in time-critical application domains, this paper outlines a new, hierarchical MAC protocol that, coupled with the Sensor Network Calculus, enables the delay and reliability properties of networks to be determined before deployment. Importantly, the protocol dynamically adapts to channel fluctuations while maintaining the anticipated delay and reliability properties.

1 Introduction and Motivation

Currently, WSNs are not used in application scenarios that require timely reaction to sensor data for two main reasons. First, there is no exact method to dimension a wireless sensor network before deployment such that delay and reliability are guaranteed. Second, most existing network components aim to be energy efficient while a few aim to minimize delay. However, none have considered a deterministic performance regarding both delay and reliability.

Given the required message transfer delay D and reliability R, our proposed deterministic framework can dimension and then operate the network to satisfy the requirements. The core of the proposed framework is a TDMA-based MAC protocol which is currently being implemented on TelosB motes [1].

2 Network Dimensioning

Assumption and Target: We assume that data readings are forwarded hop-by-hop towards a sink within a tree topology consisting of n nodes. Data is guaranteed to reach the sink not later than D and with a reliability greater than R.

Worst-Case Reliability Analysis: The network is structured such that the maximum hop distance H between any node in the network and the sink is known. In addition, we assume that the worst case bit error rate B encountered in the deployment area can be determined. Thus, we can calculate the maximum number of transmissions necessary k on a link between any two nodes such that the end-to-end reliability requirement R can be met.

Worst-Case Delay Analysis: The Sensor Network Calculus (SNC) [2] is used to determine the worst case data transport delay D, taking into account the various inter-dependencies between the sensor nodes forwarding capability, the

network traffic and the network topology. The forwarding capability is primarily defined by the MAC protocol which accommodates the total k transmissions necessary to ensure that the reliability requirement R can be met. The network traffic depends on the sensing function nodes perform.

3 Network Deployment

A new TDMA-MAC protocol based on [3] is used in the deployed network to ensure that the requirements on the delay D and reliability R determined in the dimensioning phase are met. The time axis is divided into fixed-length base units or epochs. Each epoch is subdivided into $m = k * n$ time slots. Each node exclusively owns k time slots within the epoch to transmit a message. Each message transmission is immediately acknowledged within the time slot. A node has to be active (awake) within slots assigned to its child nodes and its parent node to ensure network connectivity. The protocol is collision free and an upper bound for transmission times between two nodes is given by the size of an epoch. This feature is required for the previously described worst-case delay analysis.

Adapting to link quality: Each node must transmit a message within its first time slot in the epoch; if no data is available, a simple 'hello' message is sent. If this transmission is not acknowledged, the node will retransmit within the next slot of the k transmission slots. If the parent node does not receive a message from a child node it will start listening on the next transmission slot assigned to this node. Thus, a node has k chances to successfully transmit a message.

Resilience: In some cases it might not be possible to transmit a message within the available k transmission slots as the link quality remains poor for an extended period. In this case the grandparent of a node will become active within the slots assigned to the node. Thus, if transmission range permits, the topology will be re-organized to skip a node level. As this action reduces the maximum hop distance, the set reliability and delay targets are not compromised.

4 Conclusion

This paper has outlined a MAC protocol that initial simulations seem to match predictions from the Sensor Network Calculus and thus offers the possibility of extending the use of sensor networks into time-critical application domains. The protocol is now the focus of an implementation effort on TelosB motes.

References

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