Poster Abstract: Implementation of a Deterministic Wireless Sensor Network

Petcharat Suriyachai, Utz Roedig, Andrew Scott
{p.suriyachai|u.roedig|a.scott}@lancaster.ac.uk
InfoLab21, Lancaster University, UK

***Abstract*— Currently, wireless sensor networks (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 both 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 framework can dimension and then operate a WSN to satisfy these requirements.**

I. WSN Dimensioning and Deployment Framework

The value margin of core network parameters must be known in order to be able to perform any network dimensioning before deployment. A convenient way to describe a value margin is to specify worst-case values for the network parameters that might be encountered during normal network operation. The framework described in this section requires worst-case values for the following network parameters: channel bit error rate, network traffic and network topology. The closer the actual encountered values are to the selected worst-case parameters, the more efficient the network deployment will be as overprovisioning is reduced.

It seems unrealistic to assume that such worst-case parameters for the aforementioned network parameters are available in the planning phase of a sensor network. This is certainly true for large and random deployments in unknown environments. However, our framework targets planned deployments in known environments. The number of network nodes is limited and their location can be reasonably determined. An example application scenario which our framework can be applied to is process monitoring and control in a production plant. In such a setting, the channel bit error rate can be measured, the expected traffic can be described and the network topology can be planned.

A. Network Dimensioning

It is assumed that data is forwarded hop-by-hop towards a sink within a tree topology consisting of n nodes. The network is dimensioned such that data is guaranteed to reach the sink within time D and with a reliability greater than R.

Worst-Case Reliability Analysis : The network is structured such that the maximum hop or the worst-case 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 k necessary 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. To perform the necessary SNC calculations, assumptions regarding topology, traffic and node forwarding capabilities have to be specified. The worst case network topology is specified as Maximally Deep (O,H)-Constrained Tree [5]. The tree is specified by the maximum number of nodes n in the tree, the maximum hop distance H and the maximum number of possible child nodes O any node can have. The worst case network traffic is specified in terms of a so-called arrival curve. The arrival curve α_n describes a node's worst-case packet generation pattern which is normally related to its maximum possible sensing rate. Finally, the worst case forwarding rate β_n of each node has to be specified in terms of a so-called service curve. The service curve is defined by the medium access control protocol used and is influenced by the number of transmissions k determined in the worst-case reliability analysis.

Result: The dimensioning process allows us to balance channel characteristics (specified by B), network traffic (specified by α), topology (specified by N, H, O) and node forwarding capabilities (specified by β and incorporating k) such that application demands in the form of D and R can be met. It has to be noted that an outcome of the dimensioning process could be the conclusion that it is impossible to support an intended application scenario.

B. Network Deployment

The network has to be implemented according to the assumptions made in the above dimensioning. The assumed worst-case bounds must be certainly obeyed within the implementation. In particular, a deterministic node forwarding characteristic (specified by β and k) and a topology control mechanism that keeps the network structure within the bounds of the assumed Maximally Deep (O,H)-Constrained Tree are required. These two implementation goals are achieved by defining a specific TDMA-based medium access control protocol sharing similar concepts with [3].

The time axis is divided into fixed-length base units or epochs. Each epoch is subdivided into $m = k \cdot n$ 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. Parent and child nodes are defined statically according to the assumptions made in the dimensioning phase. 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 (to specify β).

Retransmissions: 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 extreme 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. Such topology re-forming is acceptable as the resulting tree structure is better than the Maximally Deep (O,H)-Constrained Tree assumed in the dimensioning process.

II. Implementation Details

The concept of the outlined TDMA-based MAC protocol was previously introduced in [4]. This paper extends the study into an implementation in TinyOS 2.0.2 for TelosB motes [1] which uses a CC2420 radio transceiver.

Timing: Within a time slot of the length T, the following actions have potentially to be performed. In the first phase, an incoming packet has to be transmitted or received. In the second phase, the packet that will have to be sent in the next slot must be prepared for transmission. If a packet is transmitted in the first phase, the transceiver send buffer is flushed, the message is transmitted and an ACK from the receiver has to be received. If a packet is received in the first phase, the packet has to be transferred from the receiving buffer into the microcontrollers memory. Thereafter, the packet is selected to be either enqueued in the MAC output queue or delivered to the application layer. In the second phase, either a packet from the MAC output queue or a 'hello' packet has to be loaded into the transceiver send buffer. Given a packet length of $35bytes$, the performance limitations of the SPI abstractions and the split-phase operations in TinyOS, our minimum supportable slot length is currently $9.77ms$. In theory, a slot size of about $5ms$ should be achievable if the previously described tasks are optimised.

Time Synchronisation: The MAC protocol uses the messages (either 'hello' or actual data) that a node receives from its parent in each epoch to synchronise with the sink. The proposed framework is intended for small planned network deployments with limited hop count and thus, the achieved synchronisation accuracy is sufficient.

Energy Efficiency: The transceiver has to be active in its own slot and the slots owned by parent and its child nodes. In case of necessary retransmissions, the node has to be active in redundant slots as well. Thus, the number of child nodes and the total number of slots m used defines the communication related energy consumption of a node. The energy consumption is traffic independent and can be bounded as well. This feature is desirable in a deterministic deployment.

III. Preliminary Evaluation Results

The described TDMA-based protocol was used to setup an experimental sensor network as shown in Fig 1.

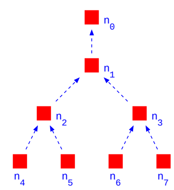

Fig. 1. Experimental Setup

The sensors were set to recorded a measurement every 3 seconds which defined the expected traffic. A bit error rate of $B = 1.431E^{-5}$ was measured in the deployment area. The worst-case reliability analysis shows that with $k = 2$ a reliability of $R = 99.10\%$ can be achieved. The worst-case delay analysis shows that $D = 570ms$ can be achieved with our MAC protocol setting of $k = 2$ and $n = 10$. Thus, the configuration uses more slots than absolutely necessary which increases the delay but improves the duty cycle and the energy consumption. Within the deployment, we measured a worst-case delay of $D' = 566ms$ and a reliability of $R' = 99.59\%$ which match the predicted bounds.

IV. Conclusion

We presented a framework which allows a sensor network to be dimensioned and deployed such that both the message transfer delay D and reliability R are guaranteed. The initial experiments show that results obtained in the network dimensioning phase match the values measured in the deployment phase. The results show that the proposed framework is useful to construct and operate deterministic wireless sensor networks.

References

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