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Wirelessly Accessible Sensor Populations (WASP)

Cross-layer Design of Low Power Medium Access and Content based Routing

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Abstract: **In this poster, we focus on the cross-layer design of a low-power traffic aware MAC protocol and a content and context based routing protocol. We describe the cross-layering aspects of the MAC-Routing framework and present the performance results on real sensor node testbed.**

Index Items: Wireless sensor networks, Traffic aware MAC, Content and context based routing, Crosslayer design, Performance evaluation

I. Introduction

Wireless Sensor Networks (WSNs) offer a huge potential in enabling new applications and business propositions across a variety of domains [1]. The WASP project [2][3], aims at narrowing the gap between academic research and industry by covering the whole range from node hardware and software, wireless network communication, towards the information distribution into enterprise systems. It targets a cost-efficient infrastructure that facilitates WSN deployment and application-driven optimization. Validation and demonstration of the developed infrastructure is actively pursued by the development of two application test beds for elderly care and herd health control. A comprehensive project overview of WASP can be found in. This poster gives a snapshot on the progress towards cross-layer optimization of networking protocols developed in the project.

II. Cross Layer Design

Context and Content-Based Routing (CCBR) [4] and Traffic Aware MAC (TrawMAC) [5] are the two protocols which are developed for publish/subscribe programming paradigm for WASP application scenarios. TrawMAC is a preamble sampling based protocol designed with the primary goal to optimize energy consumption through exploitation of shared information across protocol layers regarding traffic types, traffic loads and timing information. CCBR is a context and content based routing protocol for WSNs, which is designed to operate efficiently in mobile networks, such as WASP herd control and elderly care scenarios. Several cross-layer optimization techniques are applied to the MAC-routing stack:

A. *Support for Broadcast Traffic*

Due to the nature of the CCBR, only broadcast traffic is generated at the routing layer. TrawMAC collects the neighbourhood information and shortens the preamble length for broadcast packets. In a static network neighbourhood, nodes can have complete information about their neighbours after certain number of message exchanges. Based on the gathered wake-up schedules of all one-hop neighbours, the nodes can shorten the length of a preamble for broadcast packets by replacing the broadcast by multiple unicasts, a shortened broadcast, or a combination of these, depending on the sleep schedules of the neighbouring nodes. TrawMAC estimates the energy consumption of transmitting a broadcast message and also transmitting the possible substitutions.

1) Timing Offset

TrawMAC transmits small data packet repetitively back-to-back in a frame train fashion for duration of the maximum sleep interval of potential receivers. Since all the nodes wake up asynchronously in the network, the time-stamps of packet reception for the same packet at different nodes are different. CCBR calculates the forwarding of a packet based on the timestamp of the packet reception. Therefore, it requires that all the nodes which receive the same packet, have a same notion of the packet generation time. TrawMAC includes the timing offset between the start of the preamble transmission and the start of the packet transmission into the packet header. Using the offset, each node gets the start of the preamble transmission time based on the timestamp of the packet reception and thus implicitly synchronizes to the network.

B. *Message Queue and Data Aggregation*

Since the packets to be transmitted can be scheduled at any point of time, they are not processed in the cases when the transmitter or the channel is unavailable. Therefore, more than one data packet might be scheduled before the channel is found free for transmission. Especially for CCBR, where the forwarding packets are delayed, queued and retransmitted often, it is ideal for the MAC to be able to accept more packets than what can be transmitted at a particular time instance. A MAC queue is implemented for TrawMAC for data aggregation and minimization of control overhead. In the case of CCBR where all the packets are broadcasted, all the packets in the queue can be transmitted with only a single medium reservation. This not only conserves energy but also lowers the latency and improves the channel bandwidth utilization.

C. *Packet Cancellation*

Due to the overlapping wireless range of nodes in the network, there is a high possibility that nodes receive duplicated requests for packet forwarding. Forwarding duplicated packets increases the network traffic tremendously with increasing number of hops from source to destination. To reduce duplication, TrawMAC implements a packet cancellation mechanism taking advantages of the existence of MAC queue. When a packet is received at the MAC layer, TrawMAC checks if the same packet is already in the queue at the MAC for transmission. Identical packet is removed from the MAC queue since the message has been forwarded by other neighbouring nodes.

D. Lifetime of Packets and Prioritization

Since latency is an indeterminist factor in the stack, a mechanism is designed to impose a lifetime limit to each packet when the packet is passed to the MAC layer. The lifetime is decided at the routing layer depending on how delay-tolerant the packet is. The packet will be stored in the queue and if it is not transmitted when the lifetime expires, it is dropped and the application will be informed with a transmission fail signal. As an extension of this functionality, queue management techniques based on priority, lifetime, etc can be implemented to further optimize the stack performance. Packets with low tolerance delay level will be pushed to the front of the queue and the back-off window of that node can be reduced to increase the chance of successful channel reservation.

E. Adjustment of CCBR Timeouts based on the TrawMAC Duty Cycle

Like any preamble sampling protocol, the latency of TrawMAC directly depends upon the sampling period. A long sampling period (small duty cycle) has high latency and vice versa. CCBR has various types of timeouts in packet forwarding which are expressed as the functions of the MAC duty cycle delays as one of the cross-layer designing efforts. Both of the protocols are implemented in TinyOS 2.x and we have measured the stack performance on a multi-hop 9-node TelosB testbed and compared to our reference stack which is CCBR and tinyosMAC. Figure 1 plots delivery ratio and latency when both the tinyos MAC and TrawMAC start switching the radio on and off to save energy. Delivery ratio is very similar for the two stacks, and it is above 95% in every condition apart for the CCBR+TrawMAC stack at 250ms, where it is 87%. As for the latency, the one measured for the CCBR+TrawMAC stack is always greater than that measured for the CCBR+tinyosMAC stack. This is due to the fact that the latter stack is capable of forwarding packets very quickly without waiting for the other forwarder nodes, thus missing the opportunity of cancelling un-required retransmissions.

Although Figure 1 shows that delivery ratio and latency slightly degrade, Figure 2 quantifies the traffic reductions obtained. Here we notice how CCBR generates much less traffic when running on top of TrawMAC, with all our cross layer optimizations in place, than when running on top of the (non-optimized, duty-cycling) tinyosMAC. In particular, a much lower cost per delivered message means that the advantages in terms of traffic overcome the "disadvantages" in terms of delivery. Put in other terms, if we consider the test case using a sleeping interval of 150ms, CCBR+TrawMAC loose less than 3% of delivery w.r.t. CCBR+tinyosMAC, but

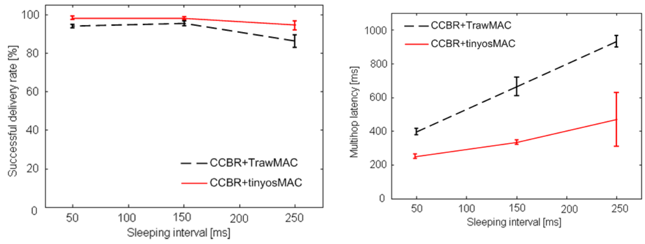

Figure 1: Successful delivery ratio and multihop latency.

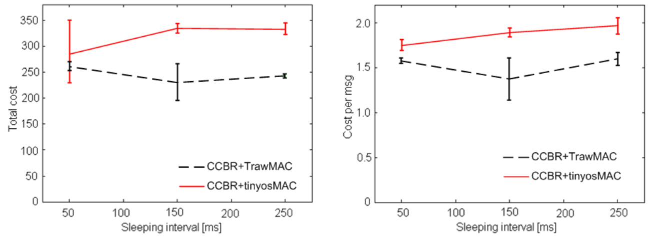

Figure 2: Total cost and cost per message.

the optimized stack uses 32% less packets to obtain this result. Since transmitting packets has a cost in terms of energy consumed, we can expect that our optimized stack will definitely help saving energy and increasing the network lifetime. Also, reduction of network traffic results in a much better scalability improving the throughput of the network for those scenarios that requires sending bursts of data.

III. CONCLUSIONS

Cross-layer optimization results of TrawMAC and CCBR show that jointly optimized stack is able to achieve higher delivery ratios at lower costs than a non-optimized stack at the expense of a slightly higher latency. The cross-optimization on real sensor node test-bed also suggests that routing protocols like CCBR can be well supported by duty-cycling MAC protocols to improve energy-efficiency and precious bandwidth consumption. While these preliminary results are very promising and show the benefits of a cross-layer design for content-based opportunistic routing, further tests are planned with more number of nodes including mobile nodes to give a thorough performance evaluation of our stack.

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