N-MAC: a Network MAC cross layer design for supporting differentiated services and simpler management mechanisms in Wireless Sensor Networks

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Abstract

This article presents N-MAC (for Network-MAC), a cross layer design framework that enables the implementation of scheduling policies by resolving some problems related to the wireless environment. N-MAC is based on CSMA/CA protocol and offers a low complexity which makes it suitable for Wireless Sensor Networks. The idea of N-MAC is that a router collects data from its children and other routers before starting their transmission. This way offers the possibility to schedule arrived packets, perform data aggregation and congestion control more easily.

1. Introduction

Offering quality of service (QoS) support in any communication network involves, among others, the implementation of a robust traffic control mechanism that classifies and fairly schedule packets according to their service class. In wired networks, many robust scheduling policies exist and some of them are widely implemented in commercial routers and switches. A popular class of schedulers is General Processor Sharing (GPS) [1] which is a theoretical model and its packet-level implementations WFQ [1], WF^2Q [2], HuFQ [3],…. However, implementing a fair scheduling policy in wireless networks is a challenging problem for several reasons [4]. First, the effective channel capacity is *location-dependant* because of the broadcast nature of the Radio Frequency. Second, the channel is *error-prone* and depends also on the location. So even in the presence of a perfect scheduler, a flow can receive less than its fair service because of errors. Finally, the main concern in wireless networks is that obtaining precise information about the flows that have to be scheduled is very difficult. For example, if the scheduler is located in the base station, scheduling down streams is easy since it has a complete knowledge about them but obtaining information about which flows have to be scheduled at which nodes in up streams is not trivial.

Wireless Sensor Networks (WSNs) are special class of wireless networks characterized by a limited processing and memory capacity and are battery supplied. These additional constraints make more difficult the development of robust scheduling policies.

2. Motivation

The main objective of this work is to propose a cross layer design for supporting differentiated services. To achieve this goal we would like to apply scheduling policies developed for wired networks (like WFQ) to a wireless network and more precisely to WSNs. The solution must respect the constraints imposed by this type of networks; low complexity and energy consumption.

To find the solution, two problems have to be solved. Firstly, how a wireless link can be shared between the end devices and the router? We consider, as a basic assumption, that end devices are attached to a router which implements the scheduler (see section 4.1). In wired networks, every node has its proper point-to-point link which is not the case in our situation since the wireless link is shared between all nodes within the same broadcast region. Besides, in order to keep simple the MAC layer, CSMA/CA protocol has to be used (on one hand, most of standards like IEEE 802.11 [9] and ZigBee [6] use it and on the other hand, other protocols like TDMA involve higher complexity and further management functions). Secondly, we must find a way to let the scheduler know about the flows to be scheduled.

Our contribution. This article presents N-MAC, a cross layer design for supporting differentiated services. In this work we have developed a framework that helps implementing such policies by proposing solutions to the problems above mentioned. In addition, N-MAC offers simpler management mechanisms like congestion control and data aggregation compared to existing WSN solutions. We leave as future work the implementation of such mechanisms.

The organization of this paper is as following: section 3 describes the related work. Section 4 describes basic assumptions and N-MAC design. Section 5 proposes a simulation study of a particular scenario. Section 6 concludes the paper.

3. Related work

This problem was firstly addressed by [4]. The authors had identified the problems of applying a scheduling policy designed for wired networks to wireless ones. They proposed a MAC protocol that implements such schedulers. The solution is centralized. It uses a TDMA like protocol for channel access which is not suitable for WSN. In [5], the authors had proposed a distributed priority scheduling policy for IEEE 802.11 standard. In the proposed mechanism, each node sends the highest priority of its own data flows to the nodes located in its broadcast region using RTS/CTS protocol. Each node maintains then, a scheduling table which is used to assess the node's priority level relative to other nodes. This solution is not suitable for WSN since it uses RTS/CTS protocol (packet lengths in WSN are comparable to CTS and RTS packets lengths) and needs a high storage memory at each node.

4. N-MAC design

4.1. Basic assumptions

We consider a wireless network composed of simple nodes and router nodes. Simple nodes are associated to router nodes while router nodes form an ad-hoc network (*Figure 1*). Cluster tree topology in ZigBee, for example, is a particular case of this topology.

All nodes use the CSMA/CA protocol which is the unslotted version proposed by IEEE 802.15.4 [4]. A simple node is associated to a router node, named its father. Simple nodes can not route messages; they send them to their respective fathers. Routers can use any ad-hoc routing protocol to establish routes between simple nodes. In the following, we will consider a deployed network: all simple nodes are associated to routers through association procedures like the one described in IEEE 802.15.4 (not described in this paper) and routes to destinations are already established (either by using a dynamic routing protocol like AODV or static one like ZigBee Hierarchical Tree Routing and its enhanced version proposed in [10]).

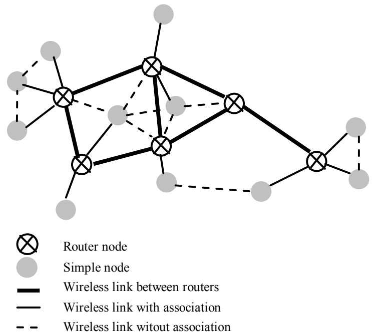

Figure 1: Network architecture

4.2. Rules

Here are the basic rules of our N-MAC design

a. Router nodes have priority to access the medium over simple nodes.
b. A router does not transmit packets one by one upon their arrival. It waits for a period of time and collects data. This period of time is called waiting period.
c. After the end of the waiting period, the router starts transmitting all packets queued in its buffer. During this period of time, called transmission period, it can not receive any data from simple devices since router nodes have the priority to access the medium which is shared with all its children.
d. At the end of transmission period, the router goes to the waiting period.

4.3. Design details

The value of *macMinBE* of CSMA/CA protocol (*macMinBE* is a constant value used to calculate the random delay that a node have to wait before sensing the channel; the Collision Avoidance mechanism) is defined to 2 for a router node and 3 for a simple node. Thus, router nodes have the priority to access the channel. The waiting period T_{wp}^{r} of a router node *r* is given by Equation (1). It depends on the number of children associated to this router node.

$$T_{wp}^{r} = \begin{cases} Rand\left[X_{\max\_snode} \times \left(N_{children}^{r} - 1\right)\right] + X_{\max\_snode}, & \text{if } N_{children}^{r} \neq 0 \\ X_{\max\_router}, & \text{otherwise} \end{cases} \quad \textbf{(1)}$$

were

$Rand(x)$ is a function that returns a random value between 0 included and x not included.

$X_{max\_snode} = 4.64$ ms

$X_{max\_router} = 3.36$ ms

$N^{r}_{children}$ is the number of children associated to router node r

X_{max_snode} is the maximum time needed by a **simple node** to perform a CCA, detects that the channel is Idle (at the first attempt) and sends the packet.

X_{max_router} is the the maximum time needed by a **router node** to perform a CCA, detects that the channel is Idle (at the first attempt) and sends the packet (Remember that the value of macMinBE of the router is smaller).

T^{r}_{wp} gives an idea about the bandwidth allocated by a router to its children. So, this parameter can be used for congestion control (see section 4.4).

At each router, there is an alternation between waiting period during which it receives data and transmission period during which it sends data. Waiting period is not constant at each round (a round is the sum of waiting and transmission period) but has a minimum value equal to X_{max_snode} if the router has children and X_{max_router} if not. The transmission period can be equal to 0 if no packets had arrived during the waiting period. It is upper bounded by the number of packets received during the waiting period and the maximum number of CSMA/CA backoffs.

4.4. Packet scheduling, data aggregation and congestion control

The idea of N-MAC is that a router collects data from its children and other routers before starting their transmission. This way, it has the possibility to schedule every received packet using any scheduling policy when the transmission period begins. The second advantage of data collection is the possibility of data aggregation within a router which improves throughput. Congestion can be detected if queue size of a router node exceeds a given Threshold. Hence before it starts to discard packets, a router node decreases the value of T^{r}_{wp} in order to reduce data throughput coming from its children.

5. Simulation

5.1. Objective and scenario description

We present in this section a simulation scenario to compare the performance of N-MAC to a simplified IEEE 802.15.4 MAC [7]. The simulator was implemented within OPNET [8] (Modeler v14.0). The objective is to demonstrate that both designs can provide the same end to end delay results. Given that result, we can state that N-MAC design is better since it offers the possibility to implement packet scheduling, data aggregation and congestion control mechanism more easily.

We consider the multi-hop network given in *Figure 2*. It simulates a building supervision system; each router is located in a room and simple nodes execute monitoring functions (fire, light, etc monitoring). All data is sent to a single manager. Simple nodes are represented by light-blue circles and transmit data to a single destination node represented by a dark-blue circle. Routers form a multi-hop network. Every router has 5 children that generate data except for router 5 which has no children. The receiver is attached to router 6.

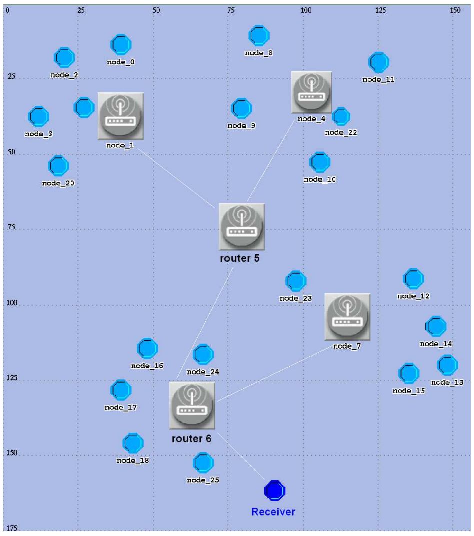

Figure 2: Considered scenario

The link capacity is equal to 250kbits/sec. Four nodes (every one is attached to a router) generate a traffic with a constant inter arrival time equal to 1sec and a constant packet length equal to 350 bits. All other nodes generate a Poisson traffic with an inter arrival time equal to 1 sec and a packet length that is exponentially distributed with an mean value equal to 400 bits. The simulation duration is equal to 1 hour.

5.2. Results

Figure 3 and Figure 4 show the global average end to end delay and throughput at the receiver node of both N-MAC and IEEE 802.15.4 MAC. Results are almost identical: same end to end delay and same throughput.

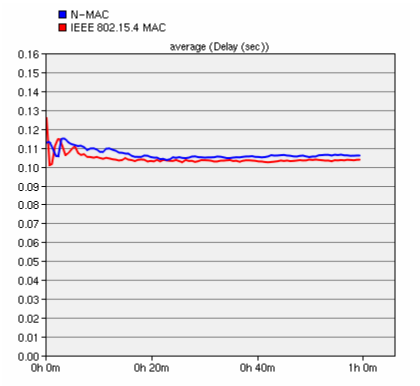

Figure 3: Global end-to-end delay

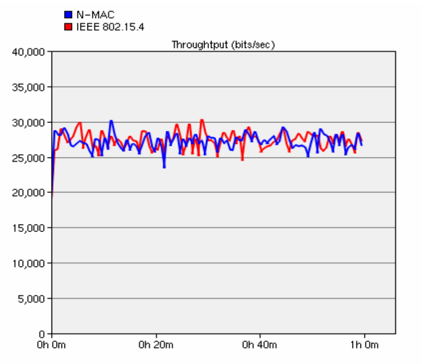

Figure 4: Throughput at receiver node

However, when we have simulated a one hop network (scenario not described in this article because of space limitation), results showed that end to end delay of N-MAC is higher than IEEE 802.15.4 MAC's one which is expected because of the waiting period that we added. So, in order to explain the results given by our scenario we evaluated the average queue size of router nodes 5 and 6. Router 5 relay messages coming from router 1 and router 2. Router 6 relay messages coming from all routers to the destination. Results are given in Table 1. In both router nodes, the queue size when using N-MAC is smaller which implies smaller queuing delay. This compensates the delay added by waiting period.

Table 1: Average queue size (in packets) of routers 5 and 6.

	Router 5	Router 6
N-MAC	0.85	3.79
IEEE 802.15.4	1.19	4.42

6. Conclusion

In this paper, we have proposed a Network-MAC cross-layer design for supporting differentiated services by enabling the implementation of scheduling policies and simpler management mechanisms (congestion control, data aggregation and grouped acknowledgement).

The key point in the design of N-MAC is the duration of the waiting period. Although the good results given by our scenario, simulations of some different scenarios show that it is not suitable for all cases; we conjecture that T_{wp}^{r} should not be a function of the number of children only. Besides, we have implemented neither scheduling policy nor congestion control mechanisms.

These two points in addition to an advanced complexity and energy consumption analysis constitute our future work.

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