TA^2I: Time Slot Access with Acknowledge Insertion

Marcel Wille and Harald Richter
Department of Computer Science, Clausthal University of Technology
Julius-Albert-Str. 4, D-38678 Clausthal-Zellerfeld, Germany
E-mail: marcel.wille|richter@in.tu-clausthal.de

Abstract

This paper introduces a new medium access scheme for ring-based,real-time local area networks which is called Time Slot Access with Acknowledge Insertion (TA^2I). It is a variant of Time Division Multiple Access (TDMA) together with a temporarily insertion of short acknowledges based on Register Insertion. TA^2I implements synchronous time slots in the form of circulating transport frames. The proposed medium access scheme tries to solve the problem of poor performance due to unbalanced network traffic with extension algorithms that allow the reallocation of unused time slots. Simulation results are presented that show the real-time capability even under overload conditions and the better performance of the extension algorithms.

1 Introduction

One of the key issues in networks with shared communication resources is a fair, efficient, and reliable medium access. Moreover, in real-time networks a maximum frame delivery time must be guaranteed. Ethernet as a popular LAN uses CSMA/CD [1] that is not appropriate for real-time communication because it can lead to non-deterministic packet collisions. Collision free protocols like FDDI [2] are too complex, have performance disadvantages or lack real-time capability [3]. Several protocols solve the real-time requirements by assigning a fixed portion of the available bandwidth to each node. Such protocols are TDMA [4, 5] or CDMA [4, 6]. These protocols achieve high performance if the traffic is stable and a priori known. But the performance drops if the traffic pattern changes. A disadvantage is that if a node does not want to send, the assigned bandwidth is lost. Now, one of the problems is to find appropriate assignments that provide a good performance with respect to throughput and latency together with real-time capability. Therefore, the proposed medium access scheme is extended by two algorithms that allow an efficient reallocation of unused time slots to provide a good performance independently of network traffic.

The scope of this paper is the presentation of a new medium access scheme for ring-based, real-time networks. Some concepts are further developments of TDMA and Register Insertion. Two extension algorithms allow a better bandwidth utilization. First results show the increased performance of TA^2I and its extensions. This paper is organized as follows: Section 2 gives an overview of related work in this area. TA^2I with the extension algorithms and the ring initialization is presented in section 3. Section 4 presents simulation results. The paper concludes with a summary and an outlook to future work.

2 Related Work

Related work to increase the performance of assignment protocols includes LTDMA (Learning-Automata-Based Time Division Multiple Access) [7], TDMA/SS (Time Division Multiple Access with Slot Skipping) [8], TTP (Time-Triggered Protocol) [9], and Flexray [10].

LTDMA grants permission to transmit data by means of learning automata. Each node has a learning automaton which contains a basic choice probability that the node gets a time slot. First, each node gets the same fraction of bandwidth and a learning algorithm updates the choice probability according to the network feedback information.

With **TDMA/SS** a time slot is skipped whenever it is not used. Hence, the next time slot can start earlier in benefit of real-time transfers. To indicate that a node does not want to send, the node has to transmit a very short protocol slot.

TTP is based on TDMA but there is no centralized master for clock synchronization. Instead, a decentralized algorithm is used and an asynchronous mode is provided to transmit event-driven messages.

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To transmit asynchronous data, a defined number of bytes are reserved in the time slot.

A communication cycle in **Flexray** is divided into a synchronous and asynchronous part. In the asynchronous part, an extension of TDMA is used (flexible TDMA). The quota for synchronous and asynchronous part is flexible. During synchronous part, every node has the possibility to send a frame. An unused time slot is wasted, which is a disadvantages.

3 Medium Access Scheme

The proposed scheme is a combination of a variant of TDMA and Register Insertion. It is called **T**ime Slot **A**ccess with **A**cknowledge **I**nsertion (TA^{2}I).

TA^{2}I guarantees real-time capability and fair bandwidth allocation among all nodes in a ring. For reliability reasons, TA^{2}I implements time slots not by a clock but by empty data frames called transport frames. No centralized master is needed for clock synchronization and time slot allocation. All transport frames are created during an initialization procedure and each transport frame is allocated to one node. The number of transport frames is called a transmit cycle. Each node can use its own transport frame to send one data frame per transmit cycle by converting it into a data frame. At the receiver the data frame is converted back into a transport frame. Short acknowledges can be injected into the ring independently from transport frames to provide reliability. The mechanism was implemented for performance reasons since acknowledges are much shorter than transport frames. An acknowledge is inserted in the ring by inserting buffer space. The destination of an acknowledge has to check if it is positive or negative. After one circulation the acknowledge is removed by the sender thus freeing buffer space.

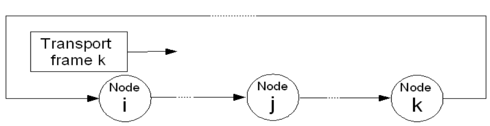

Figure 1. Reusing by an „i-to-j" transfer

Advantages of TA^{2}I are that no master is needed to regenerate global clock and assign time slots. With circulating transport frames the operability of the ring can be checked by timeout. However, the disadvantage is that the performance drops in case of unbalanced network traffic.

Furthermore, if a node does not want to send, the transport frame is lost for one transmit cycle.

3.1 Ring Initialization

To prepare the medium access with TA^{2}I, an initialization procedure has to be executed. First, the node with highest init ID is selected as master by assigning node ID 0 to it. During operation, no master is required. Second, the master generates an init frame with its node ID 0 and sends it to the next node in ring. The neighbor node increments the ID, takes it as own node ID, and assigns the new ID to the init frame. Third, the node creates a new transport frame with its own node ID, appends it to the init frame, and forward both to the next node. The same procedure repeats until the init frame returns to the master. Finally, the master converts the init frame into a transport frame and assigns its own node ID 0 to it.

Advantages are that all transport frames circulate in ascending order. TA^{2}I can be applied since transport frames represent time slots. Time slots are created without a global clock. Time slot allocation is no single point of failure during normal ring operation since no master is needed.

3.2 ETA^{2}I

The outlined disadvantages of TA^{2}I can be solved by an extension algorithm called **E**xtended **T**ime Slot **A**ccess with **A**cknowledge **I**nsertion (ETA^{2}I) that allows the recycling of unused time slots. First, each node is capable transmitting data according to synchronous TA^{2}I, thus an upper limit for frame delivery time is always guaranteed. To ensure an asynchronous usage of unused time slots, special precautions have to be made. Assume there is a directed ring with an ordered set of n nodes $\{N_i \mid i=0,...,n-1\}$ with transport frames $0,...,n-1$. Transport frame k is assigned to node k. Now, transport frame k can be reused by any two nodes i and j if the nodes are located before node k. In this case, the transport frame k is converted to a data frame by node i and converted back to a transport frame by node j before node k is reached. It is mandatory for ETA^{2}I that such an "i-to-j" transfer exists (Fig. 1). To decide whether one node is before another node the following algorithm is used.

```
If i < j:
    If j ≤ k OR k < i:
        use transport frame k for i → j transfer
If i > j:
    If i > k AND k ≥ j:
        use transport frame k for i → j transfer
```

It is not guaranteed that "i-to-j" transfers exist but if it's the case bandwidth utilization is more efficiently.

3.3 OTA^{2}I

The disadvantage of ETA^{2}I is that if no "*i*-to-*j*" transfer exists transport frames can not be reused and bandwidth is still lost. To solve this problem a second extension called **O**pen **T**ime Slot **A**ccess with **A**cknowledge **I**nsertion (OTA^{2}I) is introduced. Now, each node can grant access to its own transport frame to any other node in the ring for an arbitrary period of time. Such frames are called opened transport frames. With OTA^{2}I, the owner of a transport frame converts it into an opened transport frame if the node's send buffer is empty. Otherwise, if there is at least one data frame to send the node has to convert the opened frame back to a transport frame. Transport frames can only be converted by its owner. OTA^{2}I provides synchronous transfers if transport frames are not opened. Opened transport frames can be used by each node for an additional asynchronous transfer. In the worst case, a node has to wait one transmit cycle to use its own opened transport frame if it was already reused by another node. In this case, the node has to convert back the own opened frame to inform all other nodes that the transport frame can not be reused in the next circulation. Therefore, real-time is still maintained.

OTA^{2}I has several advantages. Opened transport frames can be reused several times in one circulation. OTA^{2}I is compatible to ETA^{2}I. The synchronous mode can be completely reverted into an asynchronous mode by opening all transport frames. In completely asynchronous mode all bandwidth can be utilized by one node.

3.4 EOTA^{2}I

Both extensions can be applied together leading to **E**xtended **O**pen **T**ime Slot **A**ccess with **A**cknowledge **I**nsertion (EOTA^{2}I). Synchronous transfers happens according to TA^{2}I. In asynchronous mode a node can either utilize all opened transport frames or an "*i*-to-*j*" transfer (if possible). The concept of EOTA^{2}I extends OTA^{2}I by allowing "*i*-to-*j*" transfers of ETA^{2}I. The combination guarantees an increased bandwidth utilization even if no transport frame is opened.

4 Simulation Results

This section shows performance comparisons between the proposed medium access scheme and its extensions. A simulation tool called RingSim and an existing protocol called CarRing [11] were used to evaluate network properties under normal and overload conditions.

Simulations are based on the following parameters: the data rate is 100 Mbit/s, all buffers were set to size 4, 64 bytes were chosen as payload length, data frames include a 12 bytes header and acknowledges have a length of 5 bytes. Sender data rates were ramped up between 0 and 100 Mbit/s. The following result parameters will be considered: throughput shows the

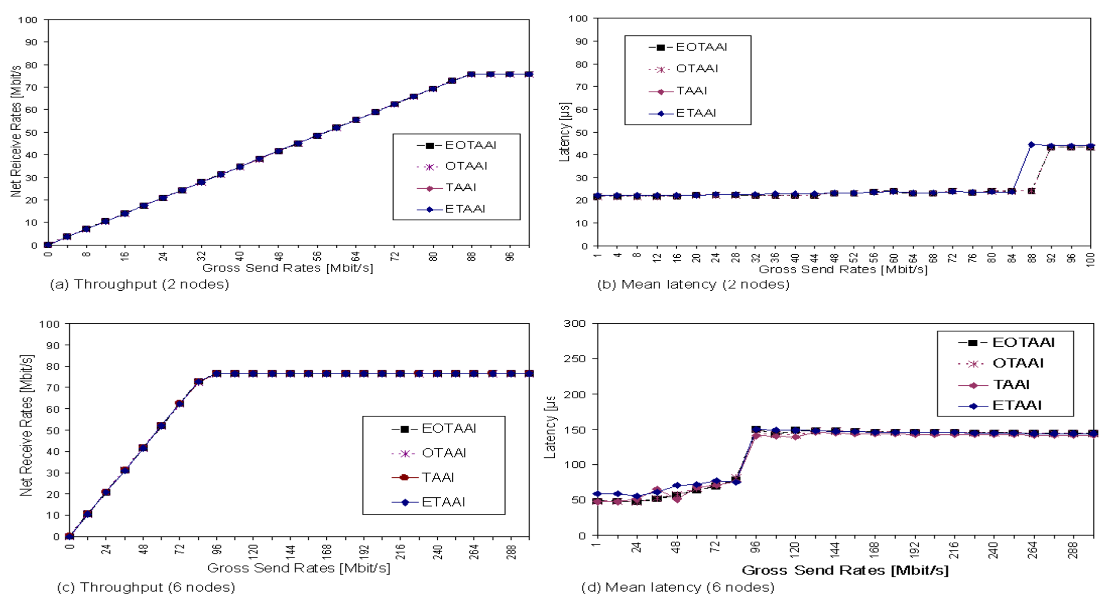

Figure 2. Throughput and latency for a ring with 2 nodes (1 sender) and 6 nodes (3 sender)

summed data rate that senders try to inject into the ring (Gross Send Rate) versus the received payload at the receiver (Net Receive Rates). Mean latencies were simulated since this is important for real-time.

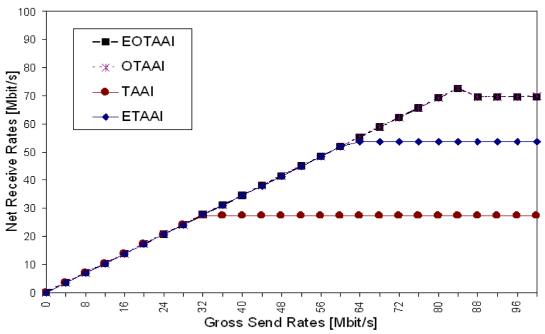

Figure 3. Throughput for scenario one

Fig. 2 shows a ring with 2 nodes (1 sender, 1 receiver) and a ring with 6 nodes (3 senders, 3 receivers). The curves for throughput are identical in Fig. 2, because each node can use at least its own transport frame and the receivers transport frame. This shows that data rates do not depend on the number of nodes in the ring. A saturation point is reached if more than 88 Mbit/s is attempted to be injected into the ring. The sender can not completely exploit the bandwidth, although he uses all time slots. The reason is that acknowledges utilize a part of the bandwidth. The mean latencies in the right diagrams are stable and predictable. Above saturation, a constant upper limit for frame delivery time is always guaranteed.

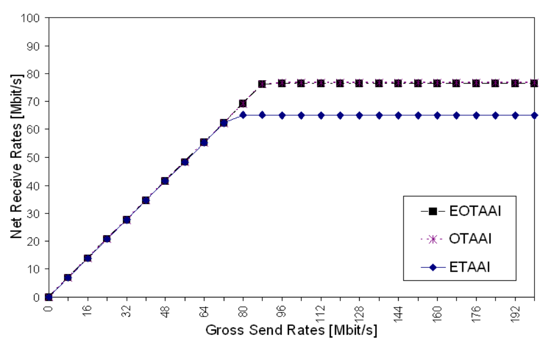

Figure 4. Throughput for scenario two

Topologies investigated in Fig. 3 and 4 contain 6 nodes and show the advantages of the extensions of TA^2I. Fig. 3 has only one active communication between node 1 (sender) and 4 (receiver). OTA^2I and $EOTA^2I$ can exploit most of the bandwidth. Except from sender and receiver, all nodes have opened its time slots. The saturation of ETA^2I drops to 60 Mbit/s, since the sender has not enough transport frames to reach the former saturation point. The saturation of TA^2I drops to 32 Mbit/s, since sender and receiver can only use its own transport frames. Fig. 4 shows differences between OTA^2I and ETA^2I. There are two active communications between nodes 1 and 3 and nodes 4 and 6. The saturation point of ETA^2I drops to 72 Mbit/s while the saturation point of OTA^2I and $EOTA^2I$ remains at 88 Mbit/s.

5 Conclusion and Future Work

A new medium access scheme for ring-based, real-time local-area networks called TA^2I was developed. It's a combination of a variant of TDMA and Register Insertion and guarantees a fair and efficient bandwidth allocation even under overload conditions. Two extensions are investigated to increase performance and exploit a maximum of the available bandwidth. With the extension algorithms an innovative solution to the problem of time slot assignment is presented. Simulation results show the performance improvement of the extensions in different traffic scenarios. Future works deal with comparisons to other assignment protocols and networks.

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