Strengthening Real Time Communication Support In Wireless Networks

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Abstract

In a distributed real-time wireless communication system the timely delivery of data in the presence of interference and competition for the medium is a key requirement. Typically this is addressed by employing time division multiple access style approaches.

The modification of a transmission schedule in such a system - in order to cater for example failed transmissions - requires the consensus of participating hosts. Reaching this consensus may in turn require the exchange of a number of messages, result in high latency for messages of failed transmissions and ultimately mean the missing of real-time deadlines.

We propose a framework that reduces the amount of coordination among participating hosts and that permits individual hosts to make autonomous localised decisions about their transmission schedule. This autonomy is achieved through a restructuring of the original TDMA approach and allows hosts to focus on the fulfillment of their individual deadlines, which in turn should increase the meeting of deadlines in the overall system.

1 Introduction

A communications architecture to support a real-time system must implement timely delivery of messages. Best effort protocols for medium access control such as Carrier Sense Multiple Access (CSMA) are unsuited to these demands. The challenge is to implement a communication system which can tolerate loss of packets while satisfying the deadline requirements of a real-time system. Typical wired real-time communication systems employ bus-based technologies such as TTP/A [6] and PROFIBUS [5] operating under a master/slave relationship.

These fixed wired infrastructures are generally reliable and may be dedicated to the real-time task. In a wireless environment the medium is shared and its properties highly variable, bit errors are significant, as such the system must accept that communications links will fail. As a result-in contrast to wired systems - wireless systems need to support the retransmission and acknowledgment of transmissions at lower layers such as the layer for medium access control.

Given the high level of coordination required between hosts in a network to implement a collision free access protocol such as TDMA: What happens if a hosts needs to retransmit a packet or send a sporadic message? This rigid structure-ideal for implementing collision free timely communication-is inflexible as hosts must agree on a modification of an established schedule potentially requiring several rounds of communication, resulting in a high latency response, insufficient for real-time applications.

In this paper we propose a protocol that supports the required flexibility by incorporating a process of localised autonomous decisions in a distributed wireless environment. This novel approach delegates partial authority concerning the arrangement of a transmission schedule to individual hosts permitting them to react to problems, primarily the need to make prompt retransmissions and also to minimise packet loss.

2 Design

The design of our approach is motivated by two goals that have been derived from available research: 1. The approach needs to avoid competition for the medium and provide time-bounded access to the medium. 2. The approach needs to be flexible, so that sporadic messages and retransmission may be handled. These goals are the basis for the our adoption of a TDMA-style approach that incorporates support for localised autonomous decisions.

Our approach hierarchical distributed time division medium access (HD-TDMA), aims to address these goals by incorporating both clearly defined fixed structures-such as slotted medium access control, while providing flexibility to accommodate infrequent, yet critical sporadic messages. In doing so, time bounded medium access is provided through the familiar TDMA structure while flexible localised scheduling is implemented making it possible to support packets of varying sizes as well as retransmissions.

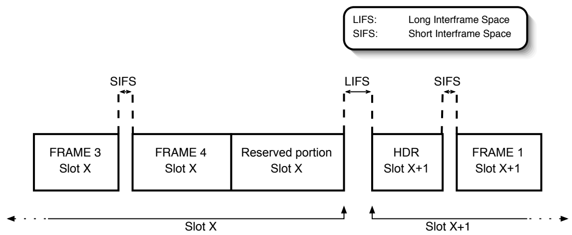

Figure 1. Different interframe gaps

Our technical motivation in the design of HD-TDMA is to minimise the amount of idle time on the medium as doing so will maximise the potential throughput. For example IEEE 802.11 offers a fragment burst mode where a station can make several back to back transmissions without the need to wait the full distributed interframe space (DIFS) interval, by only waiting the short interframe space (SIFS), giving it uninterrupted access to the medium.

In a distributed TDMA system, the interframe space is directly related to the quality of the clock synchronisation that can be achieved [4]. Thus it is desirable to reduce the number of instances where the full inter-frame gap is required as to minimise the idle time of the medium. It is thus logical to group transmissions from the same host together. As figure 1 shows in HD-TDMA a long inter-frame space (LIFS) is only used between super frame boundaries since only there does the clock synchronisation issue arise.

Having grouped transmissions together from each host, a host of course could have several groups of transmissions. We formalise the approach by introducing a slotted structure with each group of transmissions residing within one or more slots. The local host is delegated full responsibility for the transmissions within these slots and thus can add/remove/reorder/retransmit as it deems appropriate without reference to its peers thus achieving localised autonomous decisions. This enables hosts to send sporadic messages and retransmissions without first achieving consensus and thus makes it possible to achieve the time bounds required.

In the following sections, we will first discuss the details of the layer for medium access control and then explain the localised decision making process.

3 Hierarchical Distributed TDMA

HD-TDMA consists of a TDMA channel access method in which each transmitting station is allocated at least one super frame within which it can make a number of transmissions. Slot allocation is a function of the membership service which is beyond the scope of this paper, however both statically and dynamically allocated slots are supported. The use of TDMA with allocated slots eliminates contention, and thus supports time bounded medium access.

The basic structure of the HD-TDMA MAC protocol consists of a TDMA slotted structure. Each slot itself may contain a arbitrary number of transmissions from the same host thus facilitating variable packet sizes and the ability to implement acknowledged and unacknowledged packet transmission.

3.1 Super Frame

Each super frame in HD-TDMA begins with a beacon transmission to indicate the start of a super frame. This enables other hosts to synchronise with slot boundaries. The beacon is sent as a broadcast, acting as an announcement of the fact that the slot is in use by a host and contains information concerning the allocation of all slots in the system as perceived by the transmitting host as well as information used in the allocation and deallocation of slots. Thus reception of this beacon fully informs all hosts as to the status of the full TDMA cycle.

Within each super frame the local host schedules transmissions according to a local scheduling strategy. This grants considerable autonomy-allowing each host to dynamically adapt the schedule without the burden of achieving agreement with other hosts. Within the super frame packets can be of differing sizes as determined suitable by the application requirements of the sending host.

By reserving a small portion at the end of each super frame for retransmissions the protocol facilitates the support of sporadic messages as the schedule can be dynamically altered and sufficient space exists in the super frame to transmit a limited number of such messages.

The start of each super frame consists of a header or beacon frame sent as a broadcast. This contains sufficient information to uniquely identify the super frame and its transmitter. The beacon frame, will thus as a minimum include the slot number and the owners identity. Owing to the need to support a dynamic membership as well as prompt detection of failures, each beacon contains a snapshot of the allocated state of each slot. The beacon messages provide in essence a heart beat, to indicate that the station is online, and also provides information about the organisation of the entire TDMA cycle. The beacon also contains an indicator to inform other hosts as to whether or not the rest of the super frame is idle. If it is indicated as idle, other hosts may transmit sporadic messages in the remainder of the super frame using a CSMA like channel access approach. However no guarantees can be provided to the reliability of transmissions sent in this manner.

Typically, TDMA systems have fixed slot sizes. This may prove inefficient where the payload varies introducing a considerable waste of bandwidth where packets are much smaller than the allocated time for the transmission. HD-TDMA permits variable packet sizes up to a defined MTU within each super frame, thus minimising overhead and waste while maximising throughput. Both unicast packets with or without acknowledgment and broadcast are supported by HD-TDMA. In unicast a host can send a packet and receive an acknowledgments allowing positive confirmation of reception that is so critical in a real-time system.

Figure 2 illustrates a possible configuration of a HD-TDMA cycle with an N slot TDMA cycle, the contents of one slot having been expanded. The slot contains a super frame which begins with a header packet (HDR) which contains the beacon. Subsequently a number of packets of varying sizes are sent followed by some unused space. A portion of the super frame is reserved to allow for retransmissions or to accommodate sporadic messages.

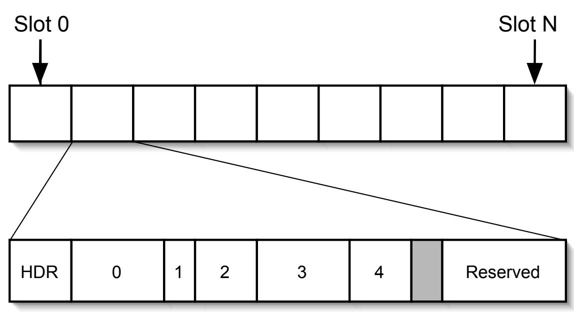

Figure 2. Relationship between the super frame, its contents, and the TDMA cycle

3.2 Slots

Each slot contains exactly one super frame which in turn contains the beacon and possibly a number of data transmissions. The number of these data transmissions that are permitted per super frame being determined by the redundancy requirements and the size of the packets.

A key requirement in a real-time communications protocol is to support not only scheduled periodic messages but also to process sporadic messages. In order to cope with sporadic messages and abnormal conditions e.g. blackouts, a small and configurable portion at the end of each super frame is reserved to accommodate such events.

4 Localised Decision Making Process

Having described our MAC approach, we now discuss the localised decision making process. This process builds on the features of the HD-TDMA protocol.

The localised decision process consists of two components: A scheduling policy and an admission control policy. These work together to ensure that packets are transmitted at a time which satisfies the real-time requirements and maximises the probability of successful reception based on known channel conditions. The admission control policy ensures that sufficient time remains unallocated to accommodate retransmissions and sporadic messages.

4.1 Scheduling policy

A host has total control over its local transmission schedule and requires no agreement from other hosts when rescheduling transmissions. There exists however a precondition that all transmissions are ordered in a way that satisfies real-time deadlines. This is a two stage process: Firstly, the host secures sufficient super slots, choosing slots which best suit the timeliness requirements of its transmissions. Secondly, to maximise the possibility of recovery from a blackout, a small portion of the end of the super frame is reserved to accommodate retransmissions.

Motivated by Bhagwat et al [3] and Balasubramanian et al [2], we consider the communications link between each host to be statistically independent. If a blackout condition occurs, e.g. a wireless channel goes through a bursty error phase, the immediate retransmission of a packet or further immediate transmissions to the effected host are considered a poor choice. However, communication links to other hosts may be unaffected. The failed communications link is marked dead for a certain duration known as the blocking period, the expected duration of the bursty error phase. Transmissions to other hosts are dynamically reordered within the super frame to take advantage of the idle medium and the statistical independence of the communication links to other hosts. Once the blocking period has elapsed transmissions are again permitted to the effected host.

4.2 Failure Detection

In any real-time system it is critical that the failure of a host is identified promptly and that suitable steps are taken to resolve the failure. To facilitate this, HD-TDMA begins each super frame with a beacon transmission. Failure to receive an expected beacon provides an indication to other hosts that the allocated owner of that slot in the super frame may have failed, or that the communications link has failed.

Hosts can then decide as to the status of a suspect host, for example consider the host failed and deallocating its slots thereby making them available to active hosts. Through consensus hosts can then decide if the host has failed e.g. failure to receive the beacon at one station may be due to bursty channel error where other hosts received the packet correctly.

Real-time messages have deadlines; thus if an expected message e.g. a periodically sampled value fails to arrive, the receiving host can-based on its knowledge of the super frame allocations-construct the latest possible reception time for known messages. If a message is not received by then a recovery protocol can be initiated. Given the slot allocation state, the reception time potentially can be earlier than the real-time deadline.

4.3 Sporadic Messages

Sporadic messages are supported through the ability of hosts to make local decisions concerning the transmission schedule of each super frame. This empowers hosts to reorder transmissions, subject to the flexibility in the message deadlines and available recovery space at the end of the frame in order to facilitate transmission of sporadic messages.

By using the portion of the super frame reserved for recovery and the ordering messages, it is possible to accommodate a limited number of sporadic messages in as prompt a fashion as possible, such that the real-time requirements of ongoing transmission are not compromised.

5 Conclusions & Future Work

We have presented our HD-TDMA MAC approach and the associated localised decision making process. We have described how it is possible to integrate channel state information into the MAC to make dynamic scheduling decisions autonomous, allowing the dynamic reordering of the transmission schedule to adapt to channel conditions and react instantly if a retransmission is required or to accommodate a sporadic message. We believe that the flexibility and dynamic adaptation of the transmission schedule we have proposed will lead to a dramatic improvement in the quality of real-time communication service that can be offered in a wireless communication environment.

Our key focus currently is the development of a scheduling approach which incorporates current communication channel conditions into the real time scheduling decision, the goal being to at all times minimse the loss of packets, minimise retransmissions and to maximise successfully transmission of packets to hosts thus strengthening the level of real time support that can be provided.

In order to verify the performance of the intelligent reaction to poor channel conditions, we are working on a implementation of HD-TDMA and the localised decision making process in the Opnet [1] simulator.

Acknowledgments

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