# Fault Recovery and Redundancy in Real-time Wireless TDMA

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## Abstract

This paper aims to address the issue of message delivery reliability in real-time, wireless communication systems. We discuss the provision of a probabilistic admissions control protocol that adapts retransmissions of frames to reflect the reliability of the medium and the required timeliness of real-time data for transmission. We utilise a two-pronged approach: firstly, admissions control to ensure transmission time is reserved such that retransmissions are possible, and secondly, an exponential backoff process to reschedule failed transmissions on a station-by-station basis. Combining these measures, we ensure the fulfillment of real-time guarantees while tolerating a limited loss of frames on the medium.

## 1 Introduction

A shared wireless communication medium with dynamically varying propagation characteristics exhibits poor delivery reliability compared to wired networks. Guaranteeing real-time communication under these conditions represents a significant challenge.

While the issue of medium contention and frame collisions can be resolved through the use of a time division multiple access (TDMA) approach, frame reception remains unreliable due to the dynamic and shared nature of the medium. Issues such as propagation path, channel fading and dynamic propagation effects impact on the reliability of frame reception and result in burst errors of varying durations.

In the presence of burst errors, the attempt to immediately retransmit a failed frame has a high probability of failure as the bursty error condition that has caused the failure may still be present. Carrier Sense Multiple Access (CSMA) protocols which view all frame loss as being caused by contention, will attempt to resend a failed frame immediately or after a slight pause.

These retransmission are likely to fail due to the continuing presence of the error conditions. Frames that are held in the transmission queue behind the current frame are delayed during this process. Typically, 3 to 4 such retransmissions will be attempted before a frame is dropped from the transmission queue.

This approach to retransmissions may be adequate for communication over shared wired media where transmission to stations A and B utilize the same medium and interfere with each other. This is not the case for transmissions over wireless media. The signals to two destinations over a wireless medium will propagate over different paths and encounter different environmental factors. This means that even though a transmission to station A failed due to an error condition, a transmission to station B may not be affected by these conditions.

Based on these observations, we propose a retransmission protocol that takes into account the characteristics of wireless medium and attempts to re-order the transmission queue following failed transmissions. An admissions control protocol is used to ensure sufficient transmission time is reserved for expected retransmissions.

Our focus in this paper is to develop an approach to accommodate the need to retransmit a number of frames while taking into account real-time criteria and frame delivery reliability. In addition to the normal, randomly distributed channel bit error rate (BER) we also consider the impact of transient propagation effects, bursty error conditions.

We propose a two tiered approach to address the issue of frame delivery reliability. Firstly, we provision transmission resources to allow for retransmissions, to recover from frame loss; secondly, we address the issue of transmission independence to overcome the impact of the bursty error condition.

The remainder of this paper is laid out as follows: In section 2 we discuss the causes of frame loss. Section 3 examines the possible approaches to retransmission. Section 4 introduces briefly our TDMA protocol which provides the scheduling flexibility to implement dynamic retransmissions. Section 5 describes our approach to combine an exponential backoff mechanism with probabilistic admission control. It also presents the analytical foundation for our approach and is followed by our conclusions.

## 2 Causes of Frame Loss

In wireless medium access control (MAC) protocols such as CSMA/CA, MACA and IEEE 802.11, transmissions are subject to contention and collisions due to numerous stations attempting to access the medium at approximately the same time.

We employ a TDMA channel access approach to provide collision and contention-free medium access. As a result, we assume that transmission errors occur only due to a fail-silent failure of a station or issues related directly to the medium e.g. background noise, transient propagation effects.

Our previous work [6] has validated this assertion with a rate of frame loss in a real world TDMA implementation of less than 0.0074% or 1 in 13,500 frames for 512 byte frames sent using IEEE 802.11 at 2Mbps.

### 2.1 Propagation Effects

Having overcome the issues of contention and collisions, we will focus now on understanding the impact of signal propagation on frame delivery reliability.

Faced with no line of sight or interference from reflection, scattering and diffraction when faced with obstacles, buildings, vehicles, lamp posts, rain and so on. This causes the signal strength and quality of transmissions to vary dramatically and make reliable signal reception difficult. A number of phenomena lead to the degradation of a transmitted signal at the receiving station:

**Reflection:** A wave that encounters an object that is very large compare to its wavelength, will reflect of its surface. This reflection is typically caused by walls, buildings and the earth itself. The energy of the wave will be reduced, leading to a shorter effective communications range.

**Diffraction:** Secondary waves are formed by an incident wave striking a sharp edge, e.g. a corner of a building. This leads to an effect where the wave is seen to ‘bend’ around obstacles.

**Scattering:** A wave that comes in contact with an object that is small compared to its wavelength, such as signs and lamp posts will scatter into a variety of wavelets.

**Doppler Shift:** Where either the transmitter or receiver are in motion a fourth effect is present, doppler shift. If a mobile host is moving, the path length to the transmitter is changing. This results in a minor change in the frequencies the receiver sees.

### 2.2 Impact of Propagation Effects

Owing to a combination of diverse factors, electromagnetic waves are subject to a very unpredictable environment. Producing extremely difficult conditions in a industrial or urban environment where a high density of obstacles exist the fact many of the mobile stations and indeed obstacles are in motion complicates matters further.

While it is possible to determine the signals path as a result of these obstacles using ray tracing as proposed by Stepanov et al [9] such an analysis holds only for a simulation. In the real world where mobility is present it is not possible to have global knowledge.

The energy of an electromagnetic wave arrives at a receiver having traveled possibly by more than one path. Each of these paths may have a different length, thus each signal may be slightly out of phase compared to a signal which would have traveled by a direct line of sight.

The signals combine at the receiver and based on the phases of the signals either constructive or destructive interference occurs. The strength of the resulting composite signal varies as mobile stations move, resulting in variable reception of frames, resulting in bursts of errors.

## 2.3 Bursty Error Characteristics

Bursty errors are characterised by two separate distributions: Firstly, a distribution of occurrence. Bursty errors occur intermittently with a significant time between each bursty event. A bursty channel is constant and reliable with relatively little bad bursts [10]. Secondly, a distribution of the length of a burst upon occurrence which has been found experimentally to follow a long-tailed distribution [11].

We consider a bursty error channel to be similar to the contention and collisions found in a multiuser, random access communications system. A non real-time data network is characterised by low bandwidth utilisation with occasional random periods of varying but short duration in comparison to the idle time of heavy utilisation. This aligns with

- Errors occur in bursts
- Random occurrence
- Lack of global knowledge
- Burst errors are detected as frame losses just like collisions and contention

Instead of contending with other stations, we are contending with the medium itself. Since the path to each station is different, the propagation effects will also different. We consider the medium characteristics to be independent for each station.

## 2.4 Dependence of Transmissions

Transmissions are not independent. If a transmission is made by station A to station B and that transmission fails if the retransmission happens within a short time frame of the first. There is a higher than average probability that the transmission will also be lost due to dynamic behaviour of a channel, bursty error or channel fading due to propagation effects. Practical evaluation by Willig et al [11] showed a 0.71 probability of a further failure following a failure for the evaluated scenario; highlighting the lack of independence of transmissions.

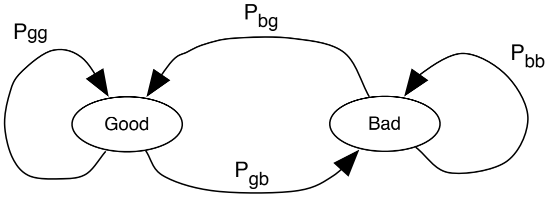

Figure 1: Gilbert/Elliot Channel Model

It is not practically feasible to derive a mathematical as transmissions are not independent, the probability of each transmissions success varies based on recent history, also the probability of success reverse transmissions e.g. acknowledgments must be considered, bearing in mind the propagation and reception conditions at both hosts are also independent, this results in a unwieldy and complex probability analysis.

The Gilbert/Elliot Channel Model [4] is a two state markov chain model, the channel is either good or bad where bad indicates a packet upon reception will have one or more erroneous bits. Probabilities classify the probability of moving from one state to another given the state of the previous packet e.g. probability of transition to bad given last packet was good. Immediately before each packet is sent the channel state is determined. The probability of remaining in the current state is typically greater than transitioning to the other state. This characteristic matches the bursty error condition trait of the channel remaining in the bad state for potentially several transmission attempts.

This somewhat simplistic but still useful model hides some of the lower level issues such as the number of erroneous bits and the point at which they occur, Willig et al [11]. Figure 1 shows the state transition diagram, the probabilities of transitions can be described as follows

| | |
|---|---|
| $P_{gg}$ | Probability given last packet was not effected by error that the next one will also be error free, good good |
| $P_{bb}$ | Given the last packet was effected by error, probability that the channel will remain erroneous, bad bad |

$P_{gb}$ Probability given last packet was not effected by error that the next one will be, good to bad

$P_{bg}$ Probability given last packet was by effected error that the next one will not, bad to good

# 3 Retransmission Approaches

Frame loss in the wireless domain is unavoidable, therefore effective recovery from frame loss is critical. When a bursty error condition results in the loss of a frame, the transmitting station must take action to retransmit the affected frame in such a manner to minimise the possibility of a second transmission failure while at the same time minimising the impact on frames to other destinations.

We have identified a number of approaches to retransmission:

- Instant Retry
- Fixed-Delay Backoff
- Probabilisitic Backoff
- Exponential Backoff
- Requeuing
- Drop of Frame

## 3.1 Instant Retry

An immediate retransmission in response to a failed transmission is often the simplest approach. In the case of a random single bit error, instant retry provides the best response. Errors on the wireless medium are not randomly distributed. They tend to cluster, resulting in a condition known as bursty error channel, an immediate retransmission may be subject to a higher rate of failure.

## 3.2 Fixed-Delay Backoff

A retransmission may have a higher rate if success if the retransmission is delayed sufficiently such that the bursty error phase has subsided. However, the statistical distribution the duration of bursty error phase exhibits a long-tailed behaviour [11]. As a result, the use of a fixed delay may be excessive in the majority of cases. A station has no knowledge concerning the duration of an error condition present on the medium or the time it has already been present on the medium and indeed how long the burst conditions where in place before an affected frame was transmitted.

A fixed-delay approach fails to take advantage of situations where a bursty error condition subsided within the time of the original transmission. In this situation, an immediate retransmission may be successful.

## 3.3 Probabilistic Backoff

A probabilistic backoff approach aims to overcome the limitations and inefficiencies of other approaches by employing a mathematical analysis of burst error phases. This analysis is applied to estimate the remaining length of a present error condition and to delay a transmission until the condition has passed.

However, deriving of a mathematical model for errors in wireless transmissions is challenging: Transmissions are not independent; the probability of a transmissions success varies depending on past transmissions; reverse transmissions e.g. acknowledgments must be considered, and the propagation and reception conditions at individual stations are independent. The probability analysis that would take these factors into consideration is complex and would have to be performed for all transmissions at runtime.

For known locations it may be possible to employ a probabilistic analysis of the expected frame loss through noise modeling, Lee et al [8] show excellent results with a closest-fit pattern matching (CPM) approach. With this knowledge a more intelligent approach may be possible avoiding the complex analysis, however the model would be required to learn and to adapt as local conditions change.

## 3.4 Exponential Backoff

Random channel access protocols such as CSMA/CA and IEEE 802.11 use an exponentially increasing backoff approach to resolve medium access contention, as we use a TDMA MAC our transmission contends only with the medium itself. As described in section 2.3 bursty errors have characteristics not dissimilar to medium contention.

While exponential backoff approaches such as those used by CSMA/CA and by IEEE 802.11 address contention between potentially many stations, in this case the transmission is contending solely with the medium.

When a transmission failure is encountered, a random exponentially increasing backoff period is calculated and all transmissions to the station in question are suspended until the backoff period expires. Exploiting the independence of the transmissions to different stations, unlike CSMA transmissions may continue to other stations while the backoff period counts down. This approach eliminates head-of-queue blocking and allows transmission to continue to unaffected stations thus maximising throughput.

### 3.5 Requeueing

A variant of the fixed-delay approach where frames are put to the back of the current transmission queue, this allows other transmissions to continue to other destinations. The time between transmission attempts varies on queue length. This approach avoids the need for an analysis and calculation of burst error durations.

No thought is given to the characteristics of the bursty error condition, frames are blindly placed at the back of the transmission queue in the hope that the bursty error condition will subside by the second transmission attempt, in light of the lack of knowledge of the conditions this approach offers a balance between the extremes of instant retransmission and a arbitrary fixed-delay.

### 3.6 Drop of Frame

In this case no retransmission occurs, the frame is simply dropped. Given the unpredictable nature of bursty error conditions, in particular the long-tailed distribution, dropping a frame may be the optimum solution instead of waiting until a bursty error condition has subsided. For example, delaying a transmission may result in missing a real-time deadline.

Thus, dropping a frame may represent a valid alternative This would prevent head-of-queue blocking and also avoid the need to reserve transmission time to accommodate retransmissions. However this may conflict with the need to satisfy real-time requirements, both in terms of deadlines and frame delivery.

### 3.7 Summary

As we have shown, several approaches to retransmission would represent a valid choice for a real-time protocol. Probabilistic backoff would provide a trade-off between immediate retransmission and fixed delays. However, the complexity of a model for error conditions and the required processing effort prevent an application of this approach. Exponential backoff appears to match the characteristics of bursty errors and represents a suitable alternative

## 4 Hierarchical Distributed TDMA HD-TDMA

Our approach to the scheduling of transmission relies on the frame layout in the HD-TDMA protocol [5]. The HD-TDMA protocol consists of a TDMA-slotted structure. Each slot is of a fixed size and may contain an arbitrary number of transmissions from one station. The individual station in charge of a slot is responsible for scheduling the individual transmissions to other stations.

This approach facilitates variable frame sizes, the ability to implement acknowledged and unacknowledged frame transmission as well as retransmissions where suitable slack is available. Each slot is considered a super frame. In the following we will concentrate on the structure of this super frame; a detailed description of the protocol can be found in [5].

### 4.1 Super Frame

The start of each super frame consists of a beacon frame sent as a broadcast. This contains sufficient information to uniquely identify the super frame and its transmitter.

Figure 2 illustrates a possible HD-TDMA cycle with an N slots or super frames. One of the superframes has been expanded to show its internal structure. Following the beacon frame, a number of frames of varying sizes are sent. A portion of the super frame is reserved to allow for retransmissions or to accommodate sporadic messages.

Each data transmission is further subdivided, the frame contents are composed of management data such as source and station mac addresses which has a CRC followed by the application data which also has its own CRC.

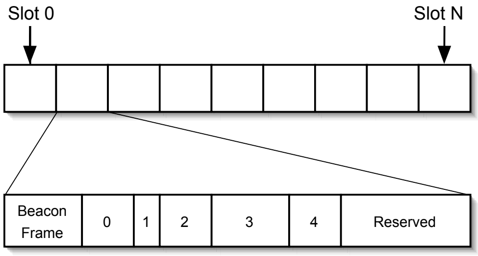

Figure 2: Relationship between the super frame, its contents, and the TDMA cycle

# 5 Transmission Scheduling

The scheduling of transmissions and the response to failed transmission is the responsibility of each individual station. In order, to fulfill real-time guarantees, a station has to schedule transmissions according to real-time requirements, admit only transmissions if they do not interfere with these requirements, and react to transmission failures. In the following sections, we will discuss the design of our admission control and the handling of transmission failures.

## 5.1 Admission Control

We employ a probabilistic admissions control protocol to ensure sufficient transmission time is reserved, to accommodate an estimated number of retransmissions. The transmission time reserved for retransmissions will vary depending on factors such as frame size, transmission speed, reliability requirements and number of frames. An evaluation is made at the point of admission based on the characteristics of currently admitted frames and the frame seeking admission.

The scheduler relies on feedback from the MAC layer to adjust its response to conditions, however the failure of a frame transmission may be the result of a large number of reasons, therefore the scheduler is forced to assume that the primary cause for a failure, the result of bursty error conditions.

### 5.1.1 DATA-ACK

An acknowledgment of a data frame, or DATA-ACK, is transmitted by the receiving station if the data has been received correctly. This provides positive feedback, assuming that data packet is received correctly by the station and that a the ACK packet is sent back, leaving three separate points of failure, packet failure outbound, station failure at receiver and packet failure return.

Any packet which is received and fails to pass the CRC test is dropped, thus it is not possible to determine did the transmission failure occur to the DATA or ACK portion.

### 5.1.2 Negative Acknowledgment

A negative acknowledgment can only be used when the receiver is expecting data by a certain time and it is not received, e.g. a CBR data flow or a scheduled transmission; it cannot be used for sporadic messages.

Such an approach cannot be applied in a real-time environment as typically the absence of packet will only be detected *after* the deadline has passed. It requires the station station to use its own transmission resources to transmit a message requesting the data, depending on the medium access approach this may not be possible.

### 5.1.3 DATA-NEGACK

Extends the acknowledgment process by providing feedback as to a failed transmission only partially received. The frame design of HD-TDMA [5] has been chosen to permit the operation of negative acknowledgments, not on the basis of expected traffic but on the partial correct reception of a packet.

Negative acknowledgments, are possible by providing a separate CRC test for both the management data and the application data, when the management portion of a frame is received correctly but the data portion fails its CRC check a negative acknowledgment is sent. Typically the data portion will be substantially larger than the management data thus is more likely to suffer from a single bit error. Detection of such errors and the use of negative acknowledgments provides a source of channel information.

### 5.1.4 Transmission Reliability Analysis

Initially, we will consider the ideal case where transmissions are independent from each other, and later show the adaption of this analysis to realistic scenarios with dependent transmissions.

Demarch et al [3] provide an insightful analysis of reliability where transmissions are independent. We utilise a similar analysis with a view to expanding and optimising its outcome. Equations 1 and 2 define the probability of the successful receipt and acknowledgment of a packet and the successful reception of packet management data only and resultant negative acknowledgment respectively.

$$p_{tx} = (1 - p_{data}) \cdot (1 - p_{mgmt}) \tag{1}$$

$$p_{ack} = (1 - p_{mgmt}) \cdot (1 - p_{mgmt}) \tag{2}$$

The reception of the management portion of a frame requires the correct reception of fewer bits than the full frame, the probability of the reception of either class of acknowledgment frame, positive or negative is greater than that of a successful transmission, thus:

$$p_{ack} > p_{tx} \tag{3}$$

Negative acknowledgments enable an informed judgment of the channel conditions. The reception of a negative acknowledgment indicates poor channel conditions. The failure to receive a negative acknowledgment indicates the channel cannot support communication even at the lowest system data rate, and may suggest the station station has failed.

After two consecutive failures to receive negative acknowledgments transmissions to the affected stations are canceled for the remaining duration of the slot, as we deem that the station station to be either out of range, failed or suffering from propagation effects.

The probability of a packet failing on the nth attempt is given by equation 4.

$$p_{fail} = p_{err}^{n_{retries}+1} \tag{4}$$

So isolating $n_{retries}$ gives us equation 5.

$$\left[ \frac{log(1 - p_{req})}{log(1 - p_{success})} - 1 \right] = n_{retires} \tag{5}$$

Performing this evaluation for each packet results in a possibly large number of required transmissions: however, would heavily constrain the number of admitted packets which can be accommodated.

If the evaluation is performed by pooling all retries together through the use of binomial theorem, as shown in equation 6, the sum total of retries requiring provisioning will reduce as it is calculated over several packet transmissions. However, this may not hold if packets have differing delivery probability and transmission probabilities e.g different packet sizes. As all packets must be assigned the same delivery probability as that of the packet with the most stringent requirements.

$$p_{sk} = \sum_{j=k+1}^{n} \binom{n}{k} \cdot p^{j} \cdot (1 - p)^{n-j} \tag{6}$$

As our TDMA MAC supports variable packet sizes such an approach would require the provision of sufficient time to transmit the largest packet the calculated number of times, resulting in inefficient use of the medium. In the presence of two differing approaches in order to maximise performance it is necessary to evaluate both and to select the most efficient result.

$$p_{rt\_requirement} \leq p_{tx\_reliability} \tag{7}$$

Where the expected delivery reliability is equal to or greater than that required by the real-time demands, zero retransmissions can be expected, this satisfies equation 5.

### 5.1.5 Calculation of Necessary Retransmissions

In order to calculate the time that should be reserved for retransmissions, we need to determine the bit error rate for the channel that is being used and the probability for retransmissions. in the following we will first present our analysis of the probability for retransmissions that then our calculations for the time that needs to be reserved for these retransmissions.

Channel bit error rate (BER) is calculated based on fixed criteria such as the signal to noise ratio, thermal noise, path loss, modulation technique, bandwidth and data rate. This calculation, however, fails to account for dynamic effects. We consider that bursty error conditions exist at most once per station per slot. We add one retransmission for each station in addition to the number calculated based on the BER loss rate using either equation 5 or 6.

## 5.2 Retransmission Protocol

In order to improve packet reliability and to simplify the analysis, we introduce the concept of a per station delay period and introduce a per station queue similar to the approach discussed by Baghwat et al [2]. As such when we encounter a failed transmission, no further transmissions will be made to the effected station until a duration of time has elapsed. This we term the blocking period.

### 5.2.1 Exponential Backoff Mechanism

As outlined in section 3.4, the use of a CSMA-like exponential backoff naturally matches the characteristics of bursty error conditions and presents an optimistic approach to overcoming the varying durations of bursty errors.

Transmissions to other stations are dynamically reordered within a super frame to take advantage of the idle medium and the statistical independence of the communication links to other stations. Once the backoff period has elapsed, transmissions are again permitted to the effected station. Should the retransmission also fail a second extended backoff period is calculated, a process continuing until either the backoff duration is such as to expire beyond the end of this transmission slot.

This approach ensures the independence of each transmission and allows us to apply analysis similar to Demarch et al [3] in a realistic environment.

# 6 Implementation

We performed our evaluation using release 14 of the Opnet [1] network simulator. Figure 3 shows the node model view of the HD-TDMA implementation in the simulator. The model comprises three distinct sections, the `app`, `gen` and `sink` modules represent the application layer. The `membership`, `queue` and `mac` represent the various components which make up HD-TDMA, its membership service and the admissions and transmission control contained in the queue module. The `rt_0` and `rr_0` modules model the physical interface onto the medium.

The simulator is configured to use IEEE 802.11b [7] physical layer characteristics, frequency, channel bandwidth and modulation to model the physical layer of the radio. The environment is modeled as an office.

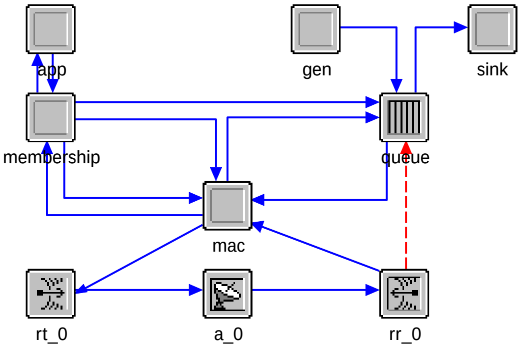

Figure 3: Opnet Node Model of HD-TDMA components

Communication between modules is through a series of FIFO queues which by default generate an interrupt at the destination when a packet is inserted, the interrupt will be processed in order of priority once the current thread of execution has completed.

At times it is necessary for a module to invoke a process on another module and be returned a value before continuing. Use is made of the Opnet access interrupt feature which allows the destination of a FIFO to raise an interrupt on the module connected to the source of the FIFO, this provides an instant switch of context to the remote module to process the interrupt, once the interrupt has been processed control returns to the invoking process thus allowing the currently executing function to collect the result from the FIFO and continue. The use of this feature avoids the need for complex sychronisation and additional states thus simplifying the developments process.

HD-TDMA is implemented as a series of state machines, one in each of the three main modules. The membership and queue modules have simple event driven state machines driven by the mac module.

Figure 4 shows the state machine contained within the `mac` module. The state machine can be divided into three pieces, the first is the necessary states and transitions to

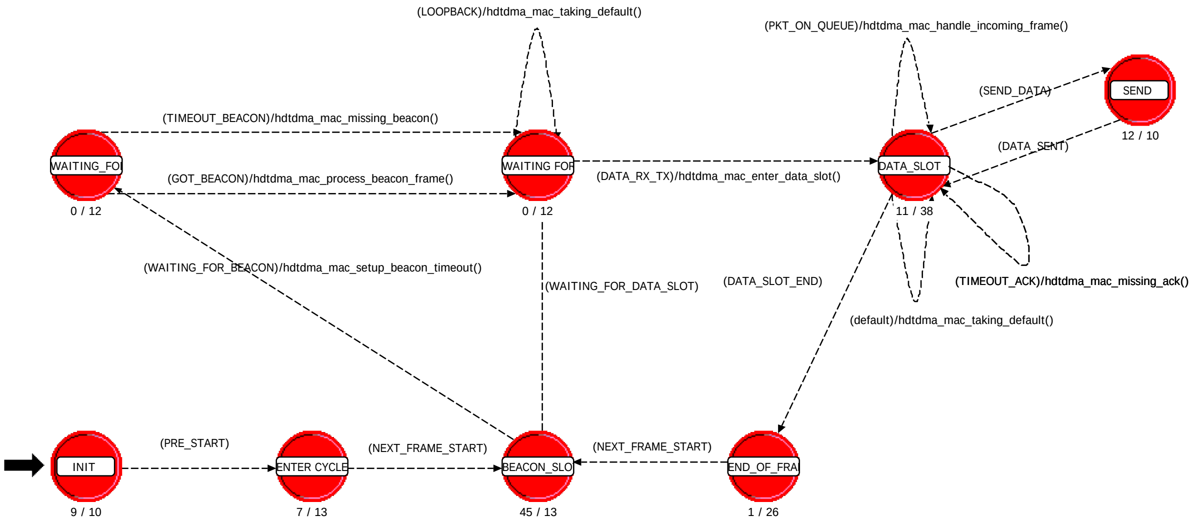

Figure 4: MAC state machine

implement the basic TDMA system, one portion handles the sending and receipt of beacon frames, the third portion manages the transmission of data.

## 6.1 Transmission Queuing

The admissions control process requires the ability to assign packets for transmission in a certain slot at a time in the future, to enable this dedicated queuing services are provided which incorporate knowledge of the membership and transmission control systems.

As the transmission resources available to the admission control system are limited to the membership service latency, frames can only be queued for transmission where confidence exists that the assigned transmission slot will be available at transmission time.

As an atomic broadcast system is used by the membership service, the atomic broadcast parameter $\Delta$ indicates the number of cycles required from issuing a membership request until it will be applied, typically a value of 2 cycles is used. As confidence exists only to a maximum of $\Delta$ cycles in the future the queue module maintains a sub queue for each transmission slot up to $\Delta$ cycles in the future. Where a request is issued to deallocate a slot no frames will be queued for transmission beyond the projected deallocation time.

When the MAC layer requests a packet the sub queue for the current transmission slot and time is selected. If the current slot has been indicated as idle the best effort sub queue will be selected.

## 6.2 Shared Memory

A key implementation difficulty was the lack of a flexible shared memory system in the simulation software. All three modules (mac, membership, scheduler) require access to the slot allocation structure. While it is possible to use a series of interrupts to produce the same result this results in significant overhead, while not effecting the outcome of simulations the simulation run time would be significantly longer and make debugging the code significantly more difficult as a result of the need for several extra states and interrupt handlers.

A shared memory structure is equivalent to an expected hardware implementation where dual port memory may be used. At the initialisation stage the membership module allocates the necessary data structures and transmits the memory address to the other modules through the FIFO queues provided as an internal management frame. Consistency of the shared data is ensured the shared memory is based on a single writer multiple readers model.

### 6.3 Summary

Our scheduling approach addressed two issues, firstly that of supporting retransmissions by provisioning transmission time and secondly overcoming bursty error conditions through the use of an exponential back off mechanism.

We initially estimate the number of retransmissions required under the assumption of each transmission being independent. We dynamically vary the amount of transmission time reserved for retransmissions, the scheduling slack based on the number, station and reliability requirements of all frames.

Secondly we implemented an exponential per station backoff to reduce the impact of bursty error channel conditions, by deferring transmissions to stations effected by the bursty error. By deferring transmissions we introduce independence between transmission attempts.

## 7 Conclusions

This paper discussed dealing with channel induced errors in a TDMA-based MAC system. We described the cause and characteristics of errors in a contention-free wireless environment, introducing the bursty error phase as a cause of errors and reception failure.

We proposed a two tiered approach in order to maximise the satisfaction of real-time guarantees in terms of on-time packet delivery. Firstly we retain a portion of retransmission time within each TDMA slot to accommodate a number of retransmissions, this reserved space dynamically varying based on the admitted packets characteristics. Secondly we adopt an exponential per station backoff to defer transmissions on communication links which are determined to be in the bursty error phase while allowing transmissions to continue to unaffected stations.

## Acknowledgments

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