Design and Implementation of a STANAG 5066 Data Rate Change Algorithm for High Data Rate Autobaud Waveforms

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Abstract: - High Frequency (HF) communication systems have been used for more than a century. However, solutions have to be designed to facilitate data communication over HF. STANAG (NATO Standardisation Agreement) 5066 is one such solution which provides an application independent ARQ (Automatic Repeat Request) bearer service for client applications. This paper describes the design and simulation of a new Data Rate Change (DRC) algorithm that uses the SNR (Signal to Noise Ratio) and the BER (Bit Error Rate) estimate to make a data rate choice. The DRC algorithm was implemented in a commercial STANAG 5066 system and tested using HF data modems and a simulated HF channel. The results of the implementation and testing show that the designed DRC algorithm gives a better performance, is quicker to adapt and is more robust than previous DRC algorithms. This is also the first DRC algorithm that has been designed to use channel information, such as the SNR and BER, to make a data rate choice.

Key-Words: - HF communication, data rate change (DRC), data communication, automatic repeat request, HF data modem.

1 Introduction

Radio communication that utilizes the bandwidth between 3 and 30 MHz is called HF (High Frequency) or *"shortwave"* communication and is especially used for communication over long distances. HF communication is still popular today because of the recovery and redundancy advantages the technology offers over satellite and more modern terrestrial implementations.

The HF radio medium has a number of key challenges when transmitting data packets. These include very low Signal to Noise Ratio radio signals, multipath fading channels, signal propagation variation based upon hour, season and sunspot cycle and a limited channel capacity.

In order to support HF data communication and perhaps even TCP/IP over HF, a need has arisen for a general, open and interoperable protocol for data applications. This is especially true for ship-to-shore communication that supports email and other PC (Personal Computer) based internet applications. STANAG (NATO Standardisation Agreement) 5066 [1] is an ARQ type protocol that controls the transmission of packets sent OTA (over the air) interface and was developed using a layered design approach, much like TCP/IP. The STANAG 5066 protocol sub-layers, as can be seen in Fig. 1, are:

Subnet Interface Sub-layer (SIS): The SIS provides a common interface for all sub-network clients that use the services provided by the STANAG 5066 node. Each client connecting to the STANAG 5066 node uses unique SAP (Subnet Access Point) number.

Channel Access Sub-layer (CAS): The CAS defines functions needed for accessing the physical channel, i.e. the radio spectrum, using a HF radio and antenna. The CAS assumes that the frequency or "channel" selection function is handled by an external process such as ALE (Automatic Link Establishment) [2], a human operator or an automated process.

Data Transfer Sub-layer (DTS): The DTS handles data transmission to a remote node and provides a reliable data link service for connected clients. The layer will ensure that D_PDUs (DTS Protocol Data Units) or *"Frames"* are delivered, based upon data exchange rules, to a remote node. The DRC (data rate change) algorithm will be implemented in this layer.

HF Modem Sub-layer: The function of the modem sub-layer is to transmit a digital signal over an analogue channel by modulating the digital signal to an audio signal at the sender and demodulating the received audio signal to a digital signal at the receiver.

ALE Sub-layer: The ALE sub-layer will be used to *make* and *break* physical links defined by an operating frequency as well as to provide a frequency selection function to the STANAG 5066 node. The ALE Sub-layer searches through a set of predefined frequencies for a remote node. When the remote node is found a link is made to this node and as soon as data transfer to the node is complete, the link is broken.

Radio Equipment Sub-layer: This sub-layer will be responsible for the tuning of the HF radio to the correct operating frequency.

Subnet Management Sub-layer: The subnet management interface is the layer that is capable of interfacing with all other layers of the STANAG 5066 protocol stack and provides management and configuration support.

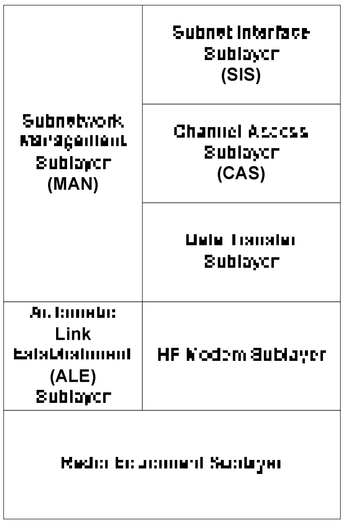

Fig. 1. Layers of the STANAG 5066 Protocol Stack.

2 Purpose of a DRC Algorithm

The HF communication medium is very diverse and challenging and this poses implementation problems for system designers trying to ensure the best amount of data throughput on a link between two nodes. For the largest throughput the following requirements have to be met:

- the best available channel must be used;
- the highest possible data rate must be used;
- the channel utilization should be high;
- the protocol overhead should be low;
- the system must adapt to changing channel conditions and avoid new link setup.

The purpose of a DRC algorithm is to select the highest possible data rate, measured in b/s (bits per second), and interleaver size to use, and to change that data rate and interleaver size based upon changing channel conditions. The best data rate and interleaver size is selected by the receiving node because the receiving node is in the best position to determine what the sending node settings should be when transmitting data to it. For the purposes of this article the waveform used is assumed to be STANAG 4539 [3]. STANAG 4539 defines a family of waveforms for data rates from 75 b/s to 12800 b/s and is made up of STANAG 4415 (75 b/s), MIL-STD (U.S. Military Standard) 110A [4] (150 to 2400 b/s) and STANAG 4539 (3200 4-PSK to 12800 b/s 64-QAM). STANAG 4539 is an autobaud waveform which means that the receiver can automatically detect the data rate and interleaver size used, which is embedded in the waveform.

3 Current Literature

3.1 DRC Procedure

It is up to the receiving node to start the DRC procedure because this node can determine the optimum rate that data should be sent to it. The DRC mechanism is initiated and controlled by the receiving node, not the sending node.

For autobaud waveforms, like STANAG 4539 and MIL-STD 110A, the DRC procedure only requires one step, called a quick data rate change. For an autobaud waveform, when one node issues the DRC request the receiving node, if it agrees with the new data rate and interleaver, immediately starts sending data at the new rate and interleaver setting, without using a handshaking mechanism.

3.2 DRC Algorithm Requirements

In [5], Trinder and Brown describe the requirements for a DRC algorithm. These requirements are:

- the algorithm should facilitate data throughput maximisation;
- the algorithm should avoid unnecessary data rate changes;
- the algorithm should adapt to rapidly changing channel conditions;
- the algorithm should minimise the time taken to reach optimum data rate, especially if handshaking is needed as with a non-autobaud waveform;
- the algorithm should be robust i.e. a change to a new data rate should not break the current communications link.

3.3 DRC Algorithms for Non-Autobaud Waveforms

Low data rate waveforms are waveforms with data rates that vary from 75 to 2400 b/s. Waveforms that fall into this category are the non-autobaud STANAG 4285 [6] waveform and the autobaud MIL-STD 110A waveform.

One of the first data rate change algorithms designed was by Trinder and Brown [5] and the goal of their DRC algorithm or mechanism was to optimise the current modem data rate based upon current channel conditions as to maximise the data throughput. The primary goal of the article in [5] was to serve as a guideline for implementers of STANAG 5066. The data rate change algorithm described uses the FER to decide to increase or decrease the modem data rate and focuses primarily on the STANAG 4285 non-autobaud waveform.

The simple DRC algorithm designed by Trinder and

Brown uses the measure of the received FER (Frame Error Rate) to select the optimum data rate ([5], [7] and [8]). This algorithm states that if the FER, i.e. the number of received frames in error over the total number of received frames, is above 50% then the data rate should be halved. In contrast, if the received FER is zero then the received data rate should be doubled, i.e. from 300 to 600 b/s or 600 to 1200 b/s. This is a very simple algorithm that is also very easy to implement. The FED STD 1052 [6] proposes that the rate increases when the FER is 0 and decreases when the FER is above 50%. Trinder and Brown do not express any opinion as to the mechanisms that should be used to determine the optimum interleaver size.

One of the major problems encountered by Trinder and Brown in their DRC algorithm implementation is one of data rate choice oscillation. This is where the modem data rate is increased because the FER is zero and in the next transmission interval the FER, at the higher data rate, is greater than 50%, which causes the modem data rate to be lowered. This oscillating effect can continue indefinitely if channel conditions remain constant. The effect is especially prevalent in a Gaussian channel, which has very steep BER curves and thus causes a very sharp change in FER with a constant SNR.

Another problem encountered in [5] involves the time required to gather enough data to accurately estimate the FER as well as the fact that even if the FER gives a fairly good indication that the data rate should be increased, it does not indicate by how much the data rate should be increased. This means that the data rate will only be increased in small steps, a very time consuming and inefficient approach.

Trinder and Brown express the opinion that a system that uses current channel conditions and better statistical estimates should be able to make better DRC decisions. The greatest problem with using such an approach is the different number of COTS (Common off the Shelf) HF modem implementations and modem interfacing capabilities offered by vendors. For example, certain manufacturers would not return any SNR or BER information to the user. As the FER is calculated by the STANAG 5066 node itself, an implementation that uses the FER as data rate decision parameter will be able to create a vendor independent DRC algorithm solution.

The OTA test results indicate that the best throughput was achieved using thresholds that increase the data rate when the FER is below 20% and decrease the modem data rate when the FER is above 50%. Trinder and Brown concluded that their simple algorithm does indeed provide a fairly reliable estimate of the optimum data rate, with the two major problems they encountered, as discussed previously being:

- data rate oscillations;
- the robustness of the DRC algorithm.

The advantage of their algorithm is that it is:

- very simple to implement;
- independent of vendor HF modem implementation.

3.4 DRC Algorithm for Autobaud Waveforms

3.4.1 Data Rate Selection

Nieto [9] and Trinder and Gillespie [10] investigated DRC optimization and STANAG 5066 performance using the STANAG 4539 waveform.

Trinder and Gillespie state in [8] that pervious work on DRC algorithms, as found in [5] and [8], indicate that:

- a simple FER based algorithm provides a reliable DRC estimate;
- an algorithm that has a min FER of 50% and max FER of 20% for lowering and increasing the modem data rate performed well during OTA testing;
- more complex algorithms that use channel information like the SNR should provide better results.

Trinder and Gillespie further state in [10] that the selection of the minimum FER of 50% for lowering the data rate is intuitive, because when the FER at 2400 b/s is 50%, it effectively means that only 1200 b/s data is being received without error and the data rate should therefore be lowered to 1200 which would produce that same throughput with 0% FER. This is only true for waveforms that have data rates that increase by a factor of two each time, as MIL 110A and STANAG 4285. STANAG 4539 waveform data rates, however, do not increase in this manner. For rates 75 – 2400 b/s STANAG 4539 does follow this model; the higher rates, however, are: 3200, 4800, 6400, 8000 and 9600 b/s.

Table 1 indicates the optimum FER decision threshold values for DRC at every data rate. The min and maximum FER threshold values for data rates from 75 to 2400 b/s remain the same (increase data rate for FER < 20% and decrease data rate if FER > 50%). The 2400 b/s data rate is not used in the algorithm implementation. When the data rate is increased from 1200 b/s, the next higher data rate is 3200 b/s, also when the data rate is lowered from 3200 b/s the next lowest data rate is 1200 b/s. This is because 3200 b/s data rate produces better performance at lower SNR than 2400 b/s. Nieto [9] evaluated DRC using different packet sizes and varying SNR values over three types of channels.

These channels were a CCIR Poor, Rician and AWGN (Additive White Gaussian Noise) channels. Nieto also states that the development of a DRC algorithm is quite complex due to the large number of variables involved.

Table 1
FER Threshold Values Used For DRC

Data Rate	Minimum FER (Decrease rate)	Maximum FER (Increase Rate)
3200	50	10
4800	35	5
6400	20	5
8000	15	2
9600	5	N/A

These include the message size, frame size, current channel conditions including SNR and BER, modem data rate and the interleaver size. The recommendations made by Nieto are:

- to group smaller messages together into larger ones;
- that packet sizes should vary between 750 to 1000 bytes;
- to only use the long and short interleaver, and only the long interleaver for fading channels;
- that data rate choices should be conservative.

Johnson [11], also produced a set of recommenddations designed to improve the performance of a STANAG 5066 system. These recommendations are:

- select the initial data rate from the current measured SNR;
- adapt the packet size based upon the current modem data rate;
- track the data rate of the sending node, i.e. the receiving node modem TX (transmit) data rate should be no less than half the sending node TX data rate

3.4.2 Interleaver Selection

The length of the interleaver has an effect on the FER, as the interleaver will counter fades found in the HF communication channel. The choice of which interleaver to use is a trade-off between the latency due to the interleaver delay and the reduced FER. Trinder and Gillespie determined in [10] that the effect of reducing the FER has less significant effect on the ARQ throughput than the increase in the latency. Trinder and Gillespie recommend always using the short interleaver and only using the long interleaver in broadcast data exchange mode.

4 DRC Algorithm Design

4.1 DRC Algorithm Inputs and Output

When a local 5066 node has finished receiving data from a remote node it has a make a decision as to the data rate and interleaver size the remote node has to use when sending data to it. The input parameters to the DRC algorithm can be seen in Table 2 and Fig. 2. Also note the element (source) that calculated the parameter value.

The output of the DRC algorithm will be (as in Fig. 2):

Table 2
Input Parameters Used For DRC

Parameter	Description	Source
Interval time (ms)	Total time of the RX interval	5066 node
Interval throughput (b/s)	Data throughput achieved in RX interval	5066 node
FER (%)	FER calculated from data in RX interval	5066 node
BER	Estimated BER from data in RX interval	HF data modem
SNR (dB)	SNR value for the RX interval	HF data modem
Interval time (ms)	Total time of the RX interval	5066 node

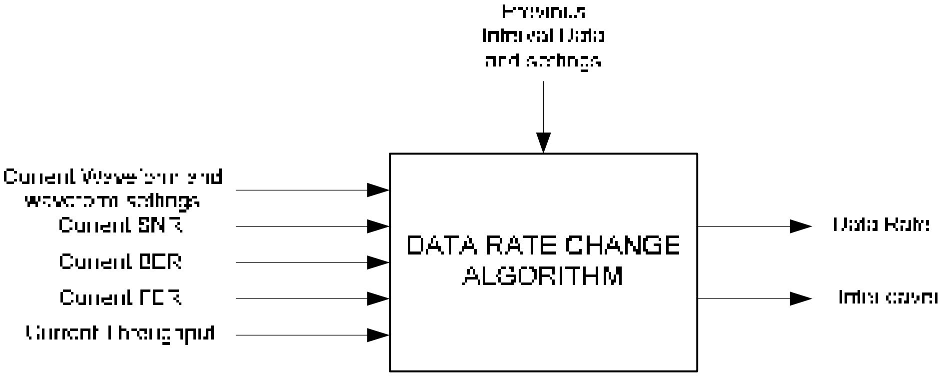

Fig. 2. DRC Algorithm inputs and outputs. The figure shows the inputs and outputs of the DRC Algorithm. The figure has two types of input information: new input data for the current interval and previous interval data. The only output is the data rate and interleaver for the next interval.

- New data rate (b/s): the data rate can be one of the following data rates, 75, 150, 300, 600, 1200, 2400, 3200, 4800, 6400, 8000 or 9600 for STANAG 4539 (Only the coded data rates are used, not the 12800 b/s un-coded rate).
- Interleaver size: the long interleaver is always used when data is transmitted. Only data acknowledgements are transmitted using the short interleaver.

4.2 DRC Decision Parameter

A DRC decision parameter needs to be chosen that accurately reflects current STANAG 5066 node performance and current channel conditions. Previous algorithms use the FER to determine the current data rate performance. The BER seems a better measure, because the BER combines the FER, SNR, Doppler spread and multipath effects into one measurable value.

Firstly, the relationship between FER and BER has to be defined. BER is measured as a running average on all data entering the HF data modem and is defined as the ratio of bits received in error as compared to the number of bits actually transmitted. BER is often expressed as the probability of a 1-bit error in a certain number of bits.

$$FER = 1-(1-BER)^{NoOfBits} \qquad (1)$$

The above equation gives the estimated FER based upon the estimated BER as measured by the HF data modem. The STANAG 5066 node is able to determine the actual FER from the data received. However, this FER measurement is subjective because fewer frames are received at a lower rate like 75 b/s than at 9600 b/s.

The time duration of the receive interval is also of concern when defining the confidence in BER, SNR and FER measurements, because the number of receive intervals and the duration of those intervals determine the accuracy of the BER and SNR measurements made by the HF modem. For a longer receive interval the confidence in the measurement is higher.

4.3 BER as Decision Parameter

The BER is chosen as the data rate decision parameter for the DRC algorithm, called the RapidM DRC algorithm 1. This DRC algorithm will be used to determine whether to increase, decrease or keep the current data rate the same. The initial BER decision thresholds used by RapidM DRC algorithm 1 can be seen in Table 3. During initial algorithm testing a problem was encountered that is similar to the problem encountered by Trinder and Brown [5], in that modem data rates chosen by the RapidM DRC algorithm 1 tended to oscillate. When the BER average is 10^{-7} the data rate is increased.

During the next receive interval, at the same average SNR and new data rate, the BER average is 10^{-4} or greater, causing the data rate to be decreased. This oscillation phenomenon is especially prevalent at lower data rates (rates 75 to 2400 b/s) on a Gaussian channel.

Table 3
BER Decision Thresholds

BER (10^-x)	Equivalent FER (from eq. 1)	Data Rate Action
<= 4	18 %	Decrease data rate
>=5 and <= 6	Between 0.2 and 18 %	Keep data rate the same
>= 7	0.2 %	Increase data rate

The reason for this is that the Gaussian channel has a very sharp drop off, as can be seen in a BER vs. SNR curve, when compared to the drop off for a CCIR Poor and CCIR Good channel. This means that there is a large change in the BER, when the data rate changes by either one data rate step up or down. For higher data rates the line for the CCIR Poor and CCIR Good channels diverge from the AWGN line, which means that the change in BER for a data rate step is not as severe as for an AWGN channel.

Another problem seen in the implementation of the RapidM DRC algorithm 1 is that the algorithm does not use previous BER measurements to predict the future behaviour of a data rate choice. Lastly, the change in SNR measurement from one interval to the next is also not used in the algorithm. The change in the SNR average coupled with the current BER measurement could be used to determine and predict a new data rate that will deliver the required BER value.

4.4 BER Channel Profile

The solution to this problem is to estimate the BER for all data rates. Based upon this estimate a data rate can be chosen based upon previous BER measurements saved in a table and changes in the SNR measurement. If the BER estimate for a data rate is not greater than a certain threshold value the data rate is not chosen. This would effectively eliminate the oscillation effect encountered.

The optimum solution would be to design and implement control logic inside the RapidM DRC algorithm 1 that would estimate the BER for each data rate by constructing a channel BER profile. A BER estimate table is constructed that contains the BER estimate for each data rate of the STANAG 4539 waveform, from 75 to 9600 b/s. When the BER estimates are plotted vs. the data rate, the BER channel profile in Fig. 3 is created. The implementation of this control logic means that the DRC algorithm structure for RapidM DRC algorithm 1 will be altered. The inputs to the algorithm and the outputs remain the same, however.

The control logic proceeds as follows: initially the BER estimate table is filled with CCIR Good channel BER estimates. After the first RX interval, based upon the current SNR, the first data rate is chosen assuming that the current channel is a CCIR Good channel.

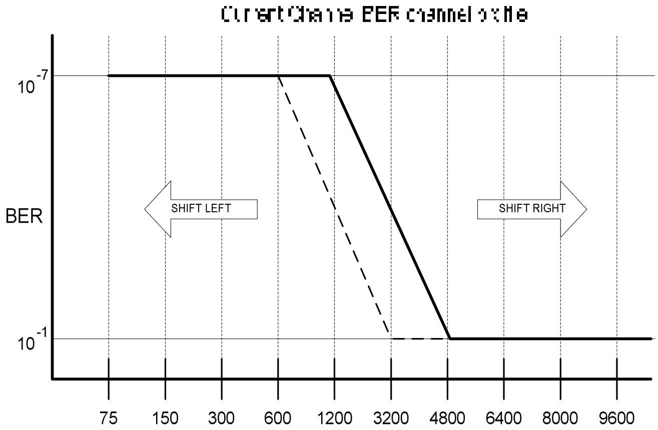

Fig. 3. BER Channel Profile. All BER measurements mad by the DRC Algorithm creates a profile of the current HF channel, and this profile will change with new BER measurements and changes in the SNR. The highest data rate is chosen that has a BER estimate above a certain threshold value.

After the next RX interval a BER and SNR measurement is made for the entire receive interval at the current data rate (inputs to DRC algorithm, see Fig. 2). The BER measurement is saved in the table and added to previous measurements at that data rate, if any exist.

If the BER measurement value is 10^{-7} and no measurement yet exists for the current data rate then the data rate is increased by one rate step (this action is called PROBE, because the algorithm is probing the next higher data rate to make a BER measurement at that data rate). Similarly, if the average BER is 10^{0} then the data rate is decreased by one data rate step, also only if no previous BER measurement were saved in the BER estimate table. If a previous interval BER measurement has been saved at that data rate the new BER measurement is added to the previous BER measurement to produce a new BER estimate and the BER estimate table is used to return the highest possible data rate that has a BER estimate that is higher than a certain threshold value (this action is called TRACK, because the algorithm tracking the current BER estimates for the channel).

The SNR change is calculated from the previous interval SNR measurement and the current interval SNR measurement. This change will change the BER estimates of data rates other than the current data rate at which the BER measurement was made. The specific BER estimates affected depends on the size of the SNR change. For a small change only the rates one rate step higher and lower than the current data rate will be changed. For a larger SNR change the BER estimates for data rates that are more than one data rate step away from the current data rate will be affected. When a large SNR change occurs all BER estimates are reset, which means that the data rate can be probed again (the entire BER estimates table is shifted either left or right based upon the change in the SNR, this action is called ACQUIRE, because the algorithm is trying to acquire the channel BER estimate profile again because of a large change in SNR).

The following two assumptions are made:

$$\frac{\Delta BER}{\Delta SNR} = 1dB\_per\_decade \tag{2}$$

$$Difference\_between\_data\_rates = 3dB \tag{3}$$

From equation 2 the change in BER for the current rate is directly proportional to a change in the SNR. This means that if the SNR increases by 1 dB the BER estimates for the rates will also increase by 1, 10^{-6} to 10^{-7}, to a maximum of 10^{-8} and conversely if the SNR decreases by 1 dB from one RX interval to the next, the BER will decrease by 1 i.e. from 10^{-7} to 10^{-6}. The maximum BER estimate value is 10^{-8} and the minimum value 10^{0}. From equation 3 the difference in SNR when moving from one rate to one rate higher or lower is 3 dB. The RapidM DRC Algorithm 1 was implemented in a Windows-based 5066 node.

5 DRC Algorithm Testing

5.1 Data Throughput Test

This test will be between two nodes, called Node 1 and Node 2, each a STANAG 5066 node that will execute on its own PC. A STANAG 5066 test client will connect to each node. Test Client 1 will send messages containing random data of varying size to Test Client 2. The message size will vary between 200 and 1000 bytes. The data (D_PDUs) will be sent in ARQ mode, thus a soft-link will be set up between Node 1 and Node 2. Node 2 will only acknowledge the received data, with ACK_ONLY D_PDUs. Node 2 will execute the DRC algorithm under test, specifying to Node 1 the TX data rate.

A HFCS (High Frequency Channel Simulator) will be used to simulate the HF channel. The RapidM HFCS is based upon the traditional Watterson-Coon HF channel model. The HF channel is characterized by multi-path propagation and signal fading. The signal at the receiver may spread by as much as a few milliseconds. A HFCS is used to model the HF channel because it is nearly impossible to reproduce actual channel conditions for channel specific tests.

A SNR scenario generator works in conjunction with the HFCS. The function of the SNR scenario generator is to change the actual channel SNR value of the HFCS based upon time elapsed in the test. The SNR scenario generator will generate a ramp input change in the SNR value of the channel for the data throughput test.

The objective of the tests is to measure the parameters of interest in Table 5. These parameters will then be used to compare the performance of the two implemented DRC algorithms, the RapidM DRC algorithm 1 and the Trinder algorithm [10]. The HF modems used in the tests are the RM6 HF Data Modems [12].

5.2 Acquisition Time Test

The setup for the data throughput and acquisition time test is similar (except for the SNR scenario generator that will not be used), the goals of the tests, however, are different. Acquisition time test will try to determine how quick the algorithm is to adapt to changing channel conditions. The test will only be conducted using the CCIR Poor channel. The test will be run two times for each DRC algorithm. In total the test will be conducted four times. The settings for the acquisition time test can be seen in Table 4. The input signal used in the test can be seen in Fig. 4. The input signal was chosen to implement large and small SNR step changes, where large SNR step changes are between 10 and 20 dB and small changes between 0 and 5 dB.

Table 4
Test Settings

Data Throughput Test	
Test settings	Test setting value
HF channels used	AWGN, CCIR Poor and CCIR Good
D_PDU Frame length	250 bytes
Message size	Between 200-1000 bytes
Test Duration	220 min
SNR start value	-3 dB
SNR end value	35 dB
Acquisition Time Test	
Test settings	Test setting value
HF channels used	CCIR Poor
Message size	Between 200-100 bytes
Test Duration	220 min

The objective of the acquisition time test is to determine the DRC algorithm response to random changes in channel conditions. The parameters if interest for the acquisition time test can be seen in Table 5.

Table 5
Test Parameters of Interest

Data Throughput Test	
Parameter name	Parameter description
Data throughput	Data throughput for the entire test duration, measured in b/s.
Data rate oscillations	Number of data rate oscillations over the entire test duration.
Algorithm robustness	Number of times a data rate change resulted in loss of link during the entire test duration. This value counts the number of times the FER value due to a data rate change is greater than 80 %.
Average BER	The average BER over the entire test duration
Average FER	The average FER over the entire test duration
Parameter name	Parameter description
Data throughput	Data throughput for the entire test duration, measured in b/s.
Acquisition Time Test	
Parameter name	Parameter description
Algorithm robustness	Number of times a data rate change resulted in loss of link during the entire test duration. This value counts the number of times the FER value due to a data rate change is greater than 80 %.
Average BER	The average BER over the entire test duration
Average FER	The average FER over the entire test duration
Total acquisition time	The sum of the interval count to reach the optimum data rate for that particular SNR, due to the change in the SNR value

Table 6
Results for Data Throughput Test

AWGN Channel

Parameter	Trinder Algorithm	RapidM DRC Algo 1
Number of Intervals	160	203
Average BER (10^-x)	5.4375	6.7401
Average FER	15.744 %	1.4313 %
Number of oscillations	61	8
Robustness	17	2
Data Throughput	2030.167 b/s	2435.536 b/s

CCIR Poor Channel

Parameter	Trinder Algorithm	RapidM DRC Algo 1
Number of Intervals	201	180
Average BER (10^-x)	5.1207	6.4429
Average FER	18.8088 %	5.768 %
Number of oscillations	52	10
Robustness	18	2
Data Throughput	1239.916 b/s	1776.474 b/s

CCIR Good Channel

Parameter	Trinder Algorithm	RapidM DRC Algo 1
Number of Intervals	210	201
Average BER (10^-x)	4.9556	6.101695
Average FER	23.80889 %	8.2271 %
Number of oscillations	36	9
Robustness	21	4
Data Throughput	912.583 b/s	1191.149 b/s

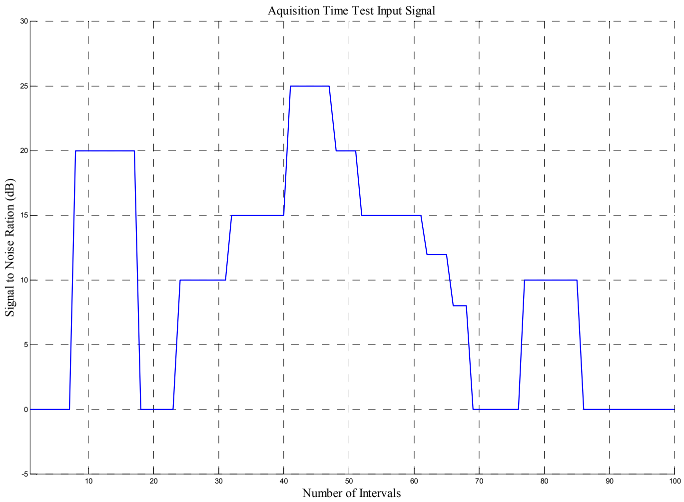

Fig. 4. Acquisition Time Test Signals (CCIR Poor Channel). Test Input Signal

6 Discussion

5.3 Data Throughput Test

Data throughput test results can be seen in Table 6 for the three HF channels. From the results of the data throughput test it can be seen that the RapidM DRC algorithm 1 has an average 400 b/s better throughput performance for every type of HF channel than the Trinder algorithm.

The RapidM DRC algorithm 1 average BER remains above 10^{-6}, while for the Trinder algorithm the average BER is always below 10^{-6} and goes so low as 10^{-4} for the CCIR Good channel. When the RapidM DRC algorithm 1 average BER is converted to the equivalent FER using equation 1 and the frame length is an average of 250 bytes. The equivalent FER for the AWGN channel is 0.036%, for the CCIR Poor channel is 0.072% and for the CCIR Good channel is 0.158%.

The reason the average and equivalent FER differ from each other is due to the frame errors the RapidM DRC algorithm 1 makes when probing new data rates. This usually causes a very large FER. The difference could also be due to the measurement accuracy of the BER measurements made in the RM6 modem, and a third reason is that the BER measurements for each interval have equal weight, this not correct, because the BER for a longer interval should have a higher weight than the BER measurement for a smaller interval. The algorithm could thus be improved by weighting the BER measurement based upon the receive interval duration.

The RapidM DRC algorithm 1 produces an average FER over the entire test duration that is below 10 %, while the FER for the Trinder algorithm is between 15 and 25% for the three HF channels. This means that the Trinder algorithm message throughput would be decreased due to more retransmissions and the extra link turnaround time lost.

The number of data rate oscillations experienced during DRC algorithm execution is also an important factor in determining performance. As the number of data rate oscillations increase so does the average FER. The average data rates oscillations for the three HF channels for the Trinder algorithm are 49.667, while for the RapidM DRC algorithm 1 the average is only 9. It seems as if the number of data rate oscillations experienced with the Trinder algorithm is dependent on the type of HF channel, while for the RapidM DRC algorithm 1 the oscillations are independent of the channel, but dependent on the amount of data rate probing done.

Lastly, when examining the robustness of the three algorithms, the average robustness over all three HF channels for the Trinder algorithm is 18.667 and for the RapidM DRC algorithm 1 it is only 2.667. Robustness is calculated as the number of data rate choices that resulted in a FER of above 80% for the next receive interval. The RapidM DRC algorithm 1's average robustness is a tenth better than the results for the Trinder algorithm. It seems that the robustness results are channel independent, which is in contradiction to the data rate oscillation results for the Trinder algorithm. It would be expected that the robustness would also be channel dependant, because the robustness of the algorithm is also dependant on the number of data rate oscillations due to the fact that it is usually during a data rate oscillation that a FER of greater than 80% is experienced. For the Trinder algorithm it would be expected that the robustness should decrease like the number of data rate oscillations for each HF channel, where the AWGN channel would have the highest robustness. The reason that this is not the case could be because the Trinder algorithm does not use previous measurements to determine the data rate for the next interval, but only current FER measurements. This means that a data rate choice could be based upon a good FER measurement in a CCIR Good channel that delivers a high SNR during only a short period of time before the channel becomes worse. Also the FER measurements made by the Trinder algorithm is not filtered with receive interval duration or frame length. One FER measurement has the same weight as any other FER measurement independent of frame length and interval duration. The results of the data throughput test indicate that the RapidM DRC Algorithm:

- has higher data throughput;
- has a higher average BER measurement;
- has a lower average FER;
- has less data rate oscillations;
- and is more robust on every HF channel than the Trinder DRC algorithm.

Table 7
Results for Acquisition Time Test (CCIR Poor)

Parameter	Trinder Algorithm	RapidM DRC Algo 1
Average BER (10^-x)	5.3069	5.9801
Average FER	23.58416 %	11.9405%
Robustness	6	4
Total Acquisition time (measured intervals)	49	19

5.4 Acquisition Time Test

The acquisition results for the CCIR Poor channel can be seen in Table VII. The data rate choice vs. the number of intervals can be seen in Fig. 5 (the dotted red line is the Trinder algorithm and the solid blue line is the RapidM DRC algorithm 1). The total acquisition time also counts the intervals that data rate choice oscillated between the optimum data rate and the next higher data rate.

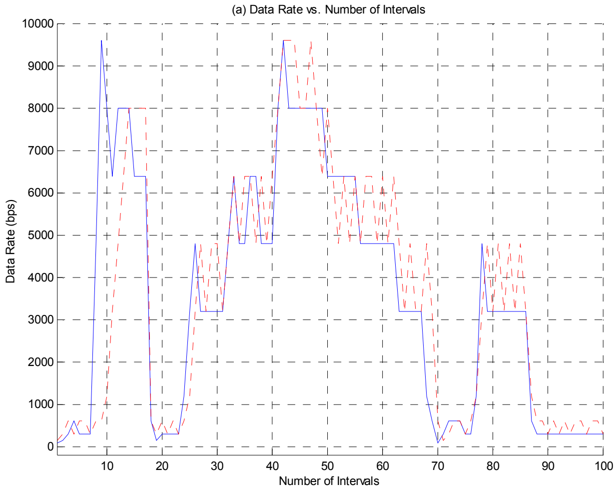

Fig. 5. Acquisition Time Test Signals (CCIR Poor Channel). Data Rate vs. Number of Intervals for the Trinder and RapidM DRC Algorithms

The RapidM DRC algorithm 1 has a lower average FER over the entire test duration than the Trinder algorithm. The average BER measurement of the RapidM DRC algorithm 1 is higher than the average BER measurement for the Trinder algorithm. The robustness results for the two algorithms are very similar. The robustness errors by the RapidM DRC algorithm were mostly made while probing the next higher data rate. This can be seen from Fig. 5 as the spikes of the solid blue line just after an SNR change.

The initial data rate spike to 9600 b/s was due to the BER estimate table being shifted right (see Fig. 3) based upon the change in SNR of almost 20 dB. It seems as if the BER estimate table has been shifted too far. The assumption of a 3 dB difference between data rates, while being true for an AWGN channel is not a very good assumption for a CCIR Poor or Good channel.

The ability to adapt to changing channel conditions is one of the advantages of the RapidM DRC algorithm 1. From Fig. 4 (b) it can be seen that the RapidM DRC algorithm tracks the 20 dB upward change faster than the Trinder algorithm and is also faster to track the downward SNR changes. For smaller changes in the input signal SNR the time taken by the algorithms are almost similar. From the figure it can also been seen that the RapidM DRC algorithm 1 does not oscillate between data rate choices. The total acquisition time for the RapidM DRC algorithm 1 is 19 receive intervals, while for the Trinder algorithm it is 49 receive intervals (note that the total acquisition time also includes data rate oscillations intervals).

6 Conclusion

The authors succeed in designing, implementing and testing a DRC algorithm, called the RapidM DRC algorithm 1, that succeeds in

- selecting the optimum data rate for current channel conditions;
- avoiding data rate oscillations;
- adapting rapidly to changing channel conditions.

The RapidM DRC algorithm 1 has produced better results than current DRC algorithm implementations found in literature and solved the data rate oscillation problem and the problem of how to rapidly adapt to changing channel conditions. The algorithm is more robust than current implementations found in literature due to the fact that it can adapt to changing channel conditions, use previous channel information to make better data rate choices. The DRC algorithm presented in this article is also the first algorithm that uses current channel condition information such as BER and SNR to determine the optimum data rate.

The main disadvantage of the RapidM DRC algorithm is that it is proprietary, i.e. only interoperable with the RM6 HF Data Modem [12]. In order to ensure that the system is interoperable with other manufacturer equipment, the FER should be used in the DRC algorithm. A FER estimate table can be constructed to determine the optimum data rate for the next receive interval. A method needs to be determined that can convert SNR changes to changes in the FER. Other channel parameters such as the SIR (Signal-to-Interference Ratio), Doppler spread, multipath and multipath spread could also be used to determine the current channel profile more clearly for use by a DRC algorithm in selecting the optimum data rate and interleaver size.

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