



Certified Wireless USB Periodic Transfer Models

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Agenda



- Wired Isochronous Model
 - Overview
 - Key Features
- Wireless Media
 - Reliability
 - Coexistence (Shared With Other Hosts And UWB Devices)
- Certified Wireless USB Isochronous Model Overviews
 - Isochronous IN
 - Isochronous OUT
- Isochronous Model Details
 - Synchronization
 - Protocol
 - Data Header Format
 - Buffer Requirements
 - Reservations
 - Flow Control
 - Error Handling Details
- **Interrupt Transfers**
- **Summary and Conclusions**

Wired USB FS Isochronous Model



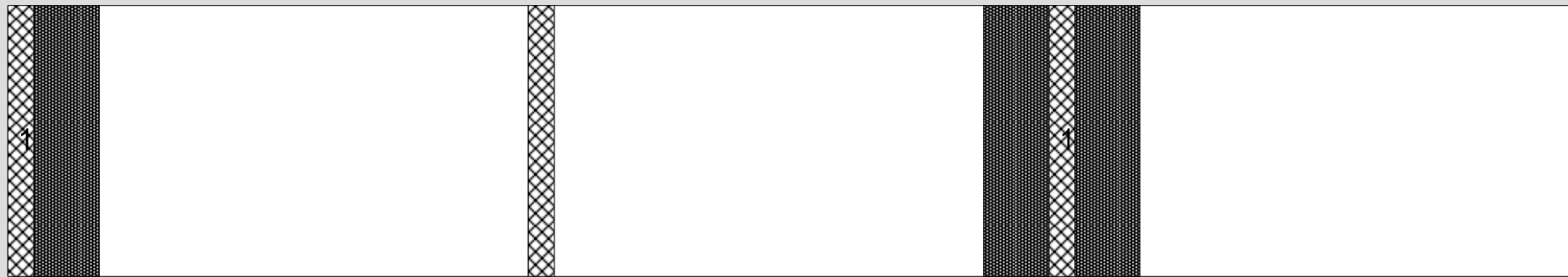
Start Of Frame



Reserved For Device A

Largest Gap Between Service Approaches 2 Frames (2 ms)

Smallest Gap Between Service Approaches SOF + Guardtime



Frame N

Frame N+1

Frame N+2

Wired USB Isochronous Feature Summary



- Guaranteed Service Attempt Every (micro)Frame
 - Reserved Bandwidth
 - Service Interval Bound 1 ms +/- ~ 1 ms
 - Typical Service Interval ~ 1 ms
- Reliability
 - Bit Error Is 10^{-9} or Better (PER 10^{-6})
 - No Retries or Handshaking Needed in Protocol
- Minimal Buffering
 - Typical Implementations Require 2 Frames (ms) of Buffering
- Synchronization
 - SOFs Occur at Regular 1 ms Intervals
- Data Delivery Time
 - Data Is Sent in Specified (micro)Frames

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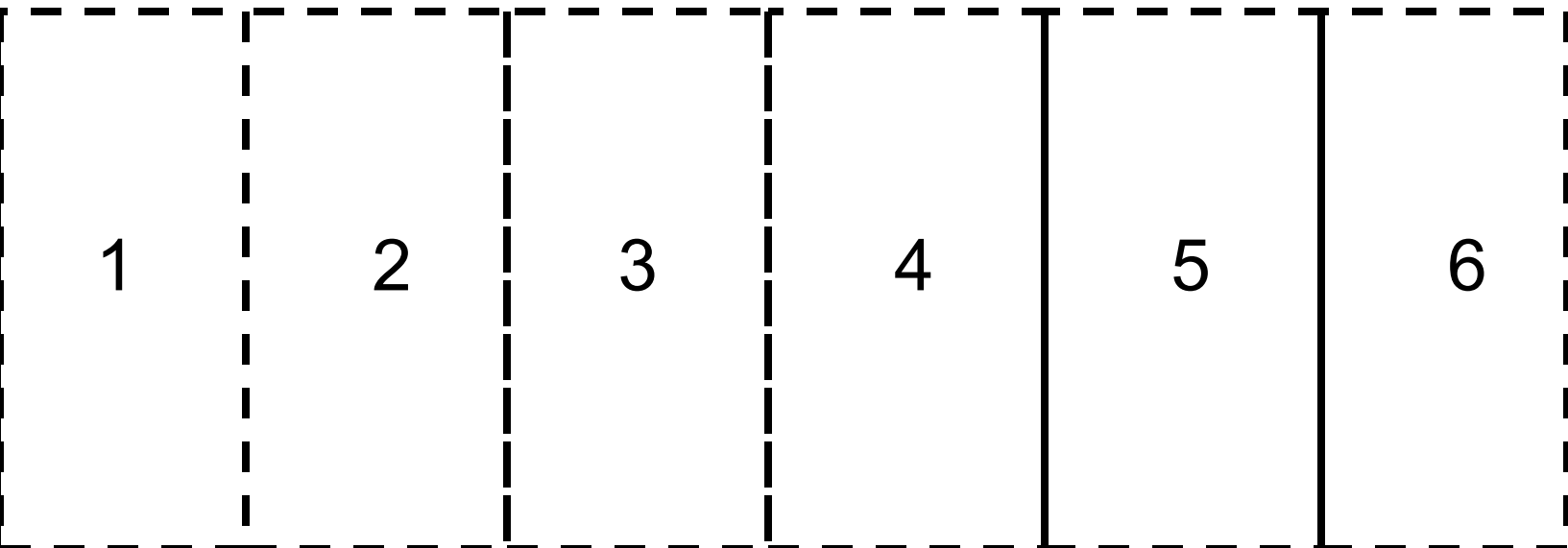
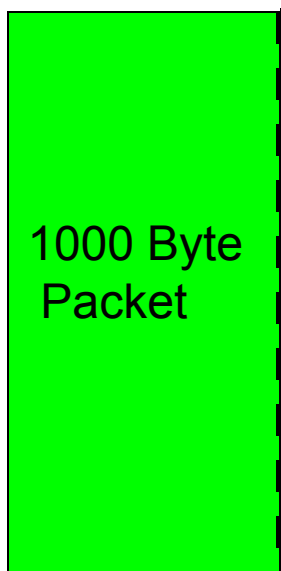
Certified Wireless USB Media Reliability



- Certified Wireless Media Is Unreliable (vs. Wired)
 - Average PER rates will reach 10%+
 - UWB Phy Specification Specifies an 8% PER or better for 90% of paths is “good” for several simulation cases
 - This Makes PER Rates 100,000 X + Wired Rates
 - Events could cause much higher short term error rates
 - People walking between transmitters
 - Adjacent channel interference
 - Merging Device Clusters
- Some streaming formats require Packet Error rates on the order of 10^{-5} or better

Certified Wireless USB Media Reliability – Example

Guaranteeing 10^{-6} With 10% PER

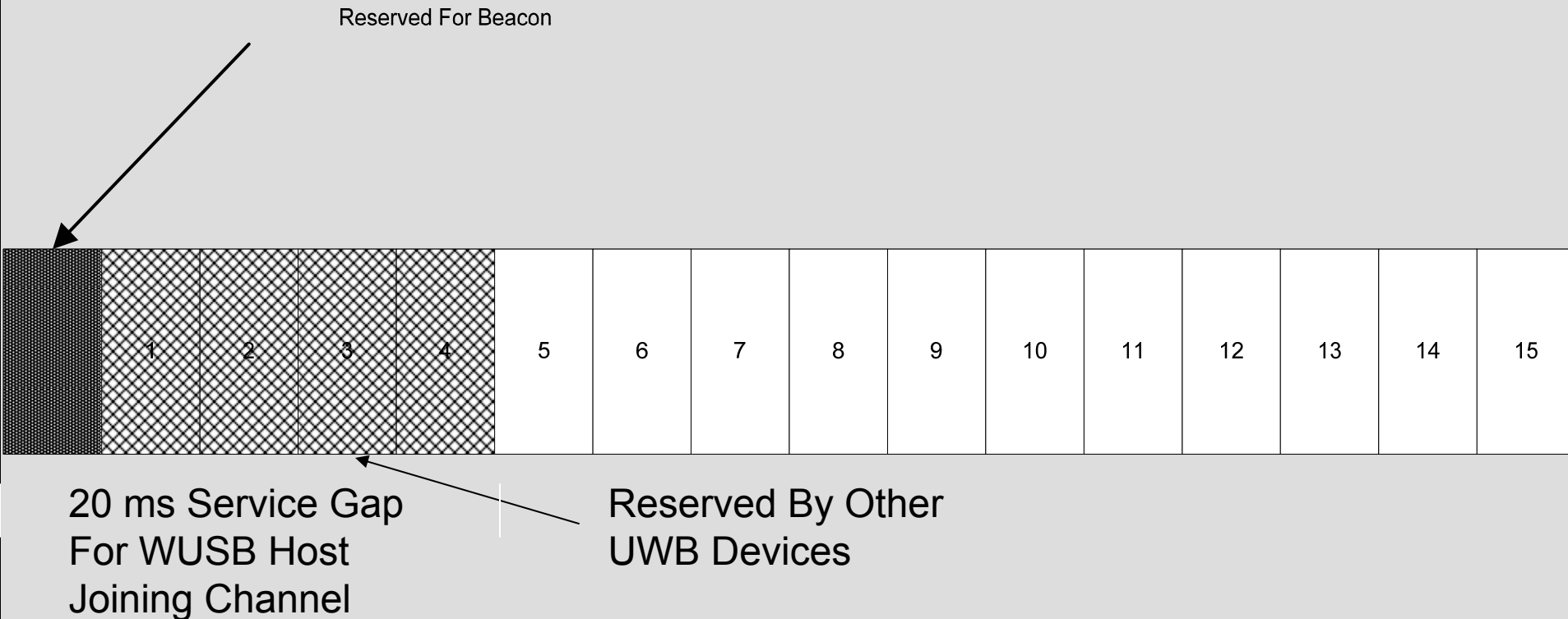


To Guarantee 10^{-6} Reliability You Need To Be Able to Retry Up to 6 Times in a Slot

Need Handshaking (Allow Reclamation Of Unused Time)

This Still Breaks with Short Term Error Bursts

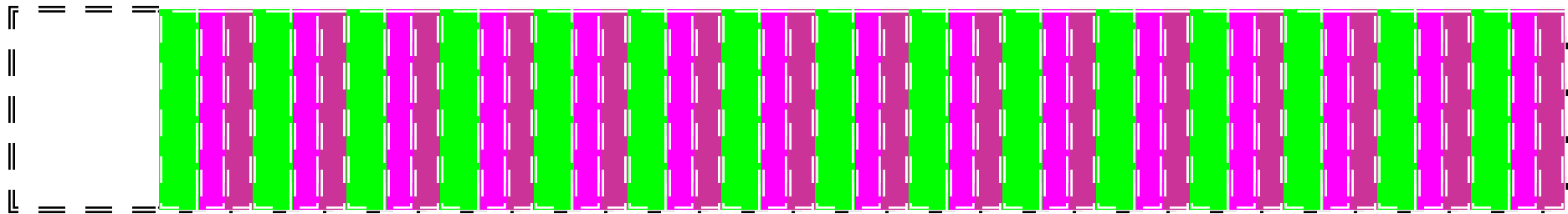
UWB Shared Media – Big Continuous Reservations Cause Problems



A Host Can Not Require an Empty Channel for Iso Support

Beacon Reservation and Other UWB Device Reservations Must Be Assumed

Service Interval



Reserved
For Beacs
~ 4 ms

Dev A
2 ms
Reservation

Dev B
1 ms
Reservation

Dev C
1 ms
Reservation

Intervals

6 ms (Beacon)

2 ms (Non-Beacon)

Intervals

7 ms (Beacon)

3 ms (Non-Beacon)

Intervals

7 ms (Beacon)

3 ms (Non-Beacon)

CWUSB Channel Limits Maximum Service Interval to 8 ms (beacon)
or 4 ms (non-beacon).

Possible Service Intervals $\sim 4^*, 8, 16, 32, \dots$

Service Interval Encoding



<i>Interval Value</i>	<i>Requested Service Interval (ms)</i>
6	4.096*
7	8.192
8	16.384
9	32.768
10	65.536
11	131.072
12	262.144
13	524.288
14	1048.576
15	2097.152
16	4194.304

Service interval bounds are multiples of 128 microseconds (not 125)

CWUSB Iso Model Cannot Be the Same as Wired



- Media
 - Unreliable. Error Rates 100000X+ higher than wired
 - Shared. Larger service interval bounds
- Key Wired Characteristics Can Be Preserved
 - Synchronization (Provided By SOF Or Better)
 - Effective Reliability (10^{-5} PER or Better)
 - Same level of reliability can be achieved under most circumstances
 - Definition of when packets need to be delivered changes

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Example – Isochronous In Device



Video Camera

Data From Device
Function

Data Buffer = X ms



Data To Host ←

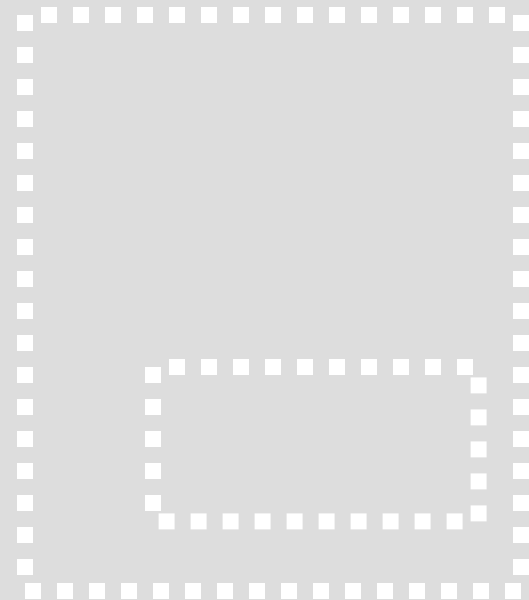
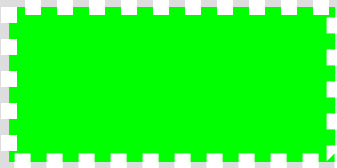
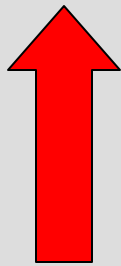


Example – Isochronous In Stream Start Up



Iso In Device

1. Host Obtains Device Buffer Size and Starts Asking For Data
2. Host Buffer Fills
3. Host Starts Using Data

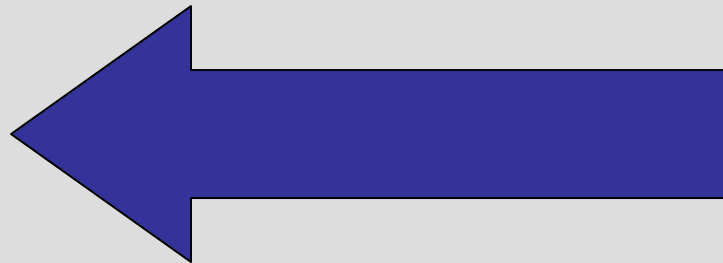
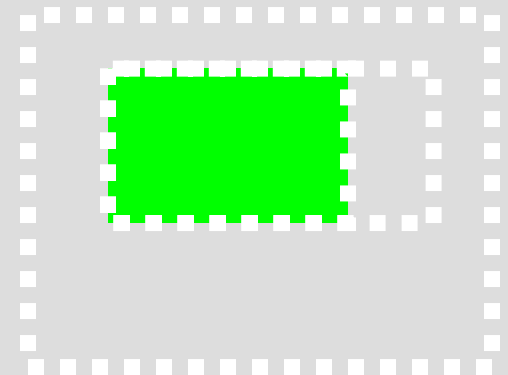
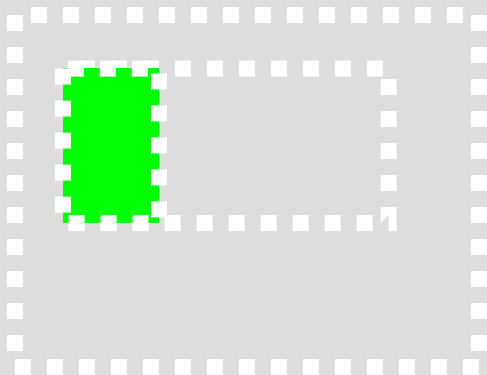
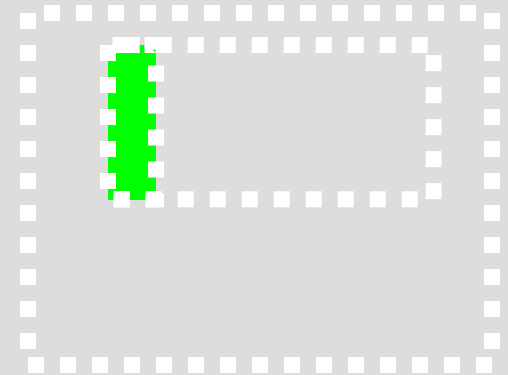
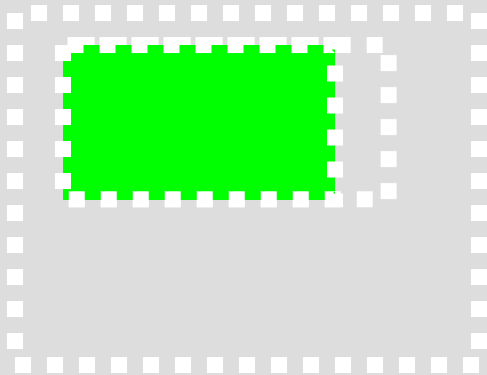


Example – Isochronous In Normal Operation



Host

Device



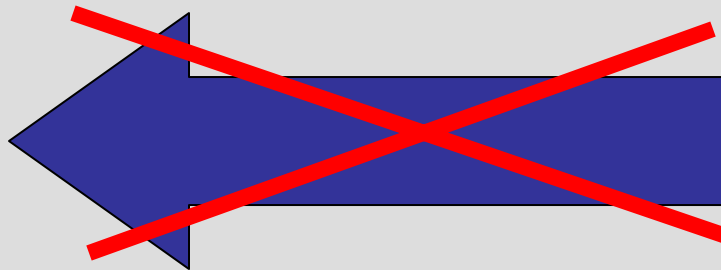
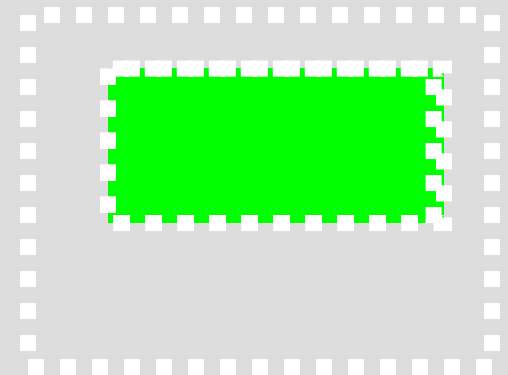
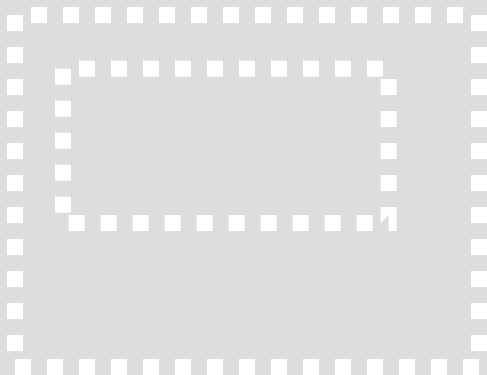
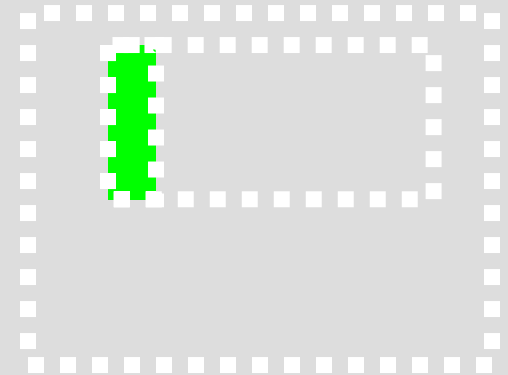
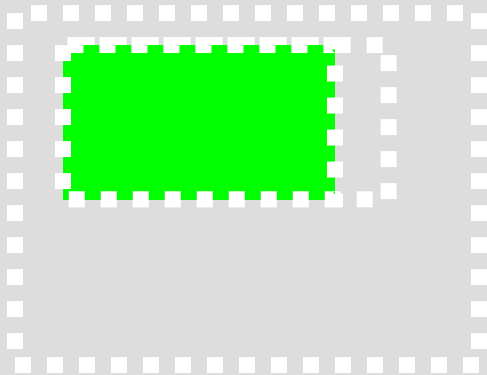
Host Can Use Approximate Buffer State to Adjust Scheduling

Example – Isochronous In Error Case



Host




Device

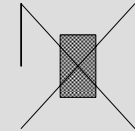
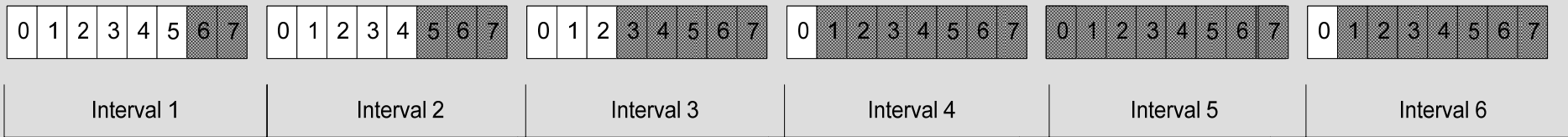
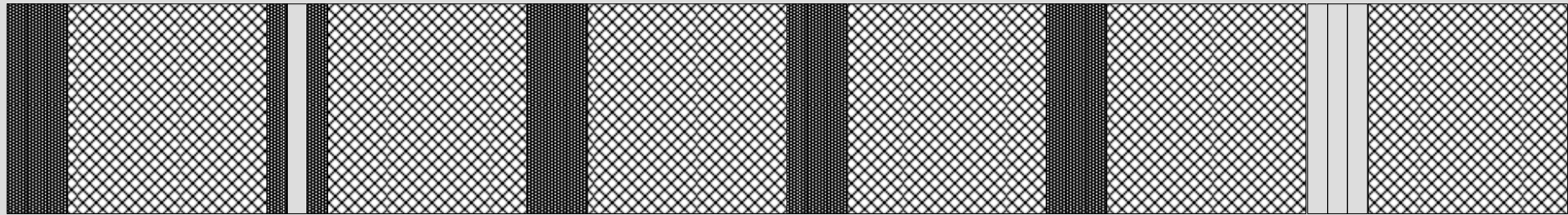


Data Is Only Discarded When Buffer Overflow Happens on Device

Isochronous In – Data Discard and Recovery



-  Packet Sent
-  Packet Smashed
-  Not Reserved For Iso Stream



Isochronous Out Device



Music Player

Output Buffer = X ms

Data From Host



Isochronous Out Stream Start Up

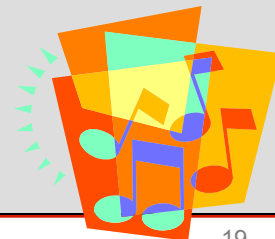
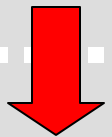
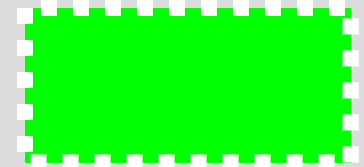


Host

1. Host Obtains Device Buffer Size and Starts Sending Data
2. Device Output Buffer Fills
3. Device Starts Data Output



Iso Out Device

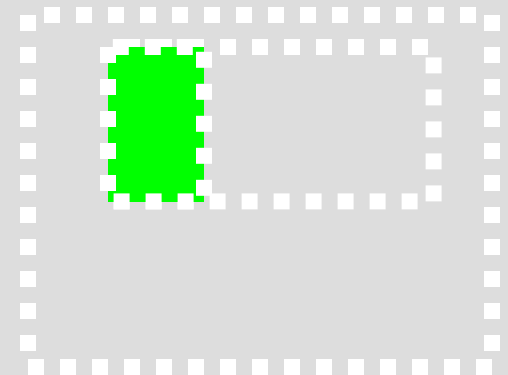
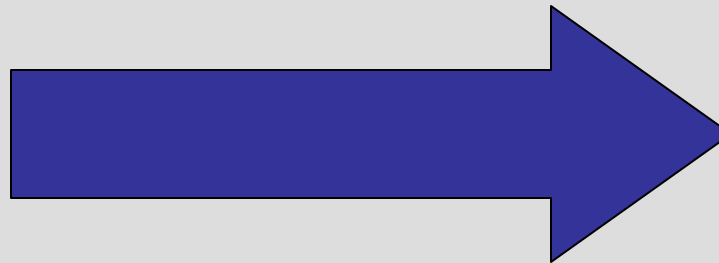
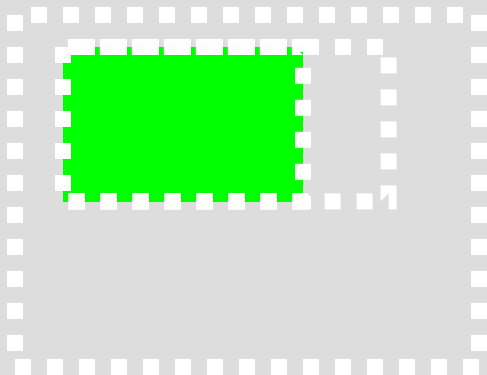
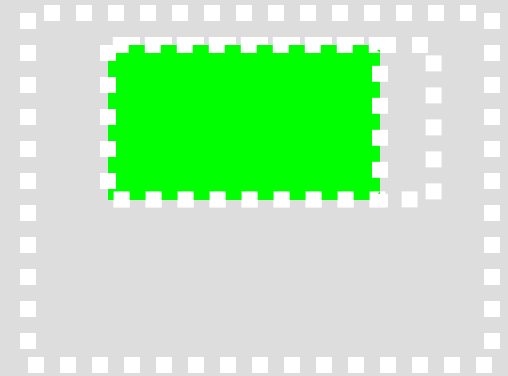
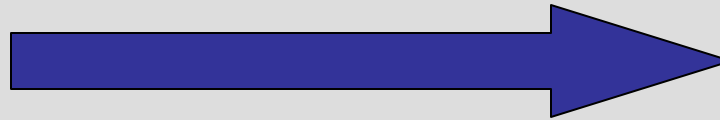
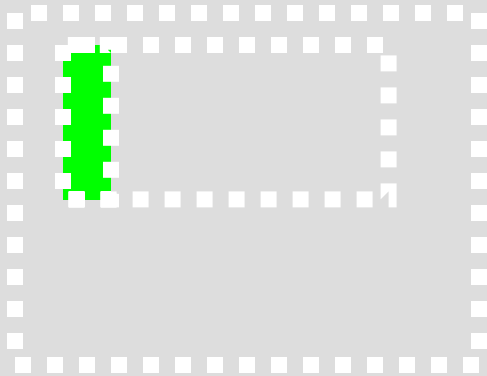


Isochronous Out Normal Operation



Host

Device



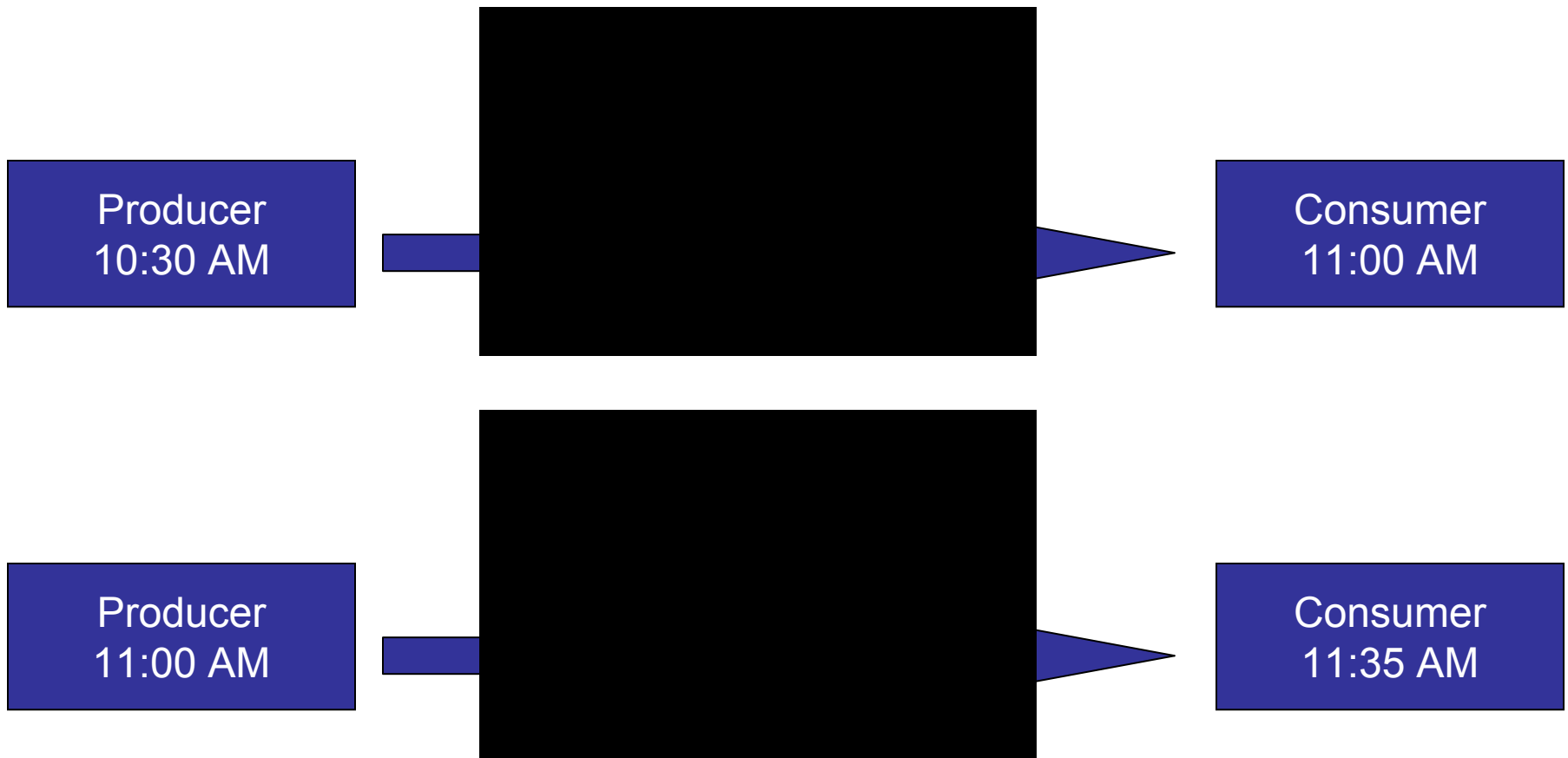
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Synchronization – Problem Statement



Producer and Consumer Have to Have a Way to Have Clocks That Drive Production and Consumption at the Same Rate/Time or Buffers Overflow/Underflow

Synchronization – Time Stamp Location

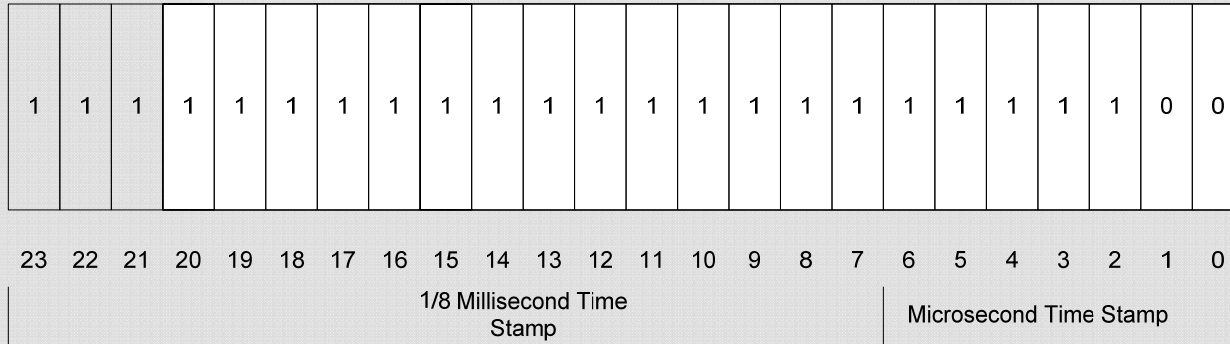


2	1	2	2	3	VAR	VAR	... VAR
CWUSB App Code	MMC Code	Next MMC Time	Reserved	WUSB Channel Time Stamp	IE[0]	IE[1]	IE[N]

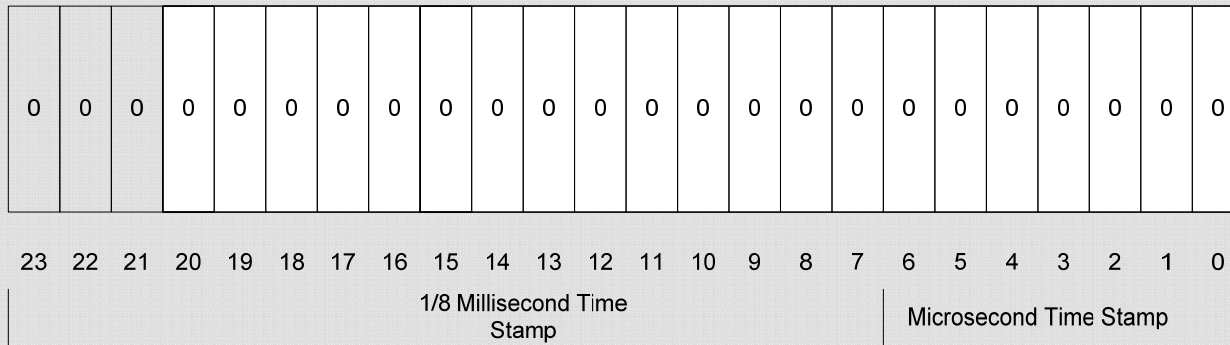
3 Byte Time Stamp in MMC

Time Stamp Reflects Start Time for MMC Transmission on the Air

Synchronization – Time Stamp Format



Microsecond Before Wireless USB
Channel Time Rollover



Microsecond After Wireless USB
Channel Time Rollover

Microsecond Granularity Time Stamp to Easily Map to Wired USB Time

Synchronization – Time Stamp Accuracy



- PHY TX Delay
 - Variable
 - Not a Problem if Factored in Correctly
- PHY TX Delay Uncertainty
 - Worst Case
 - +/- 2 Pclock
 - +/- 30 Nanoseconds
 - Best Case
 - +/- 1-2 Nanoseconds
- CWUSB Infrastructure Requires MMC Transmission to Start on Microsecond Boundaries
- MMC Time Stamp Must Be Accurate
 - Time Stamp in MMC Must Be Host Time at Start of MMC Transmission
 - Accuracy requirement is +/- 40 Nanoseconds (Worst Case + Padding)
 - Based on Host Free Running 20 ppm Clock

MMC Wireless USB Channel Timestamp Provides Wired Equivalent Clock and Accuracy

Protocol Details



- Retries
 - PER Can Be 10%
 - Short Term Error Bursts Can Occur
 - Retries Required
- Handshaking
 - Wired Reliability Would Require ~6 Broadcasts Per Packet Without Handshaking
 - Short Term Error Burst Tolerance Still Problematic
 - Handshaking Required
- Data Discard
 - Only Required by Physical Limitations
 - Buffer Size

Isynchronous Protocol Is Nearly Identical To Wireless Bulk Protocol

Protocol Details In Protocol Presentation

Isochronous Header Format



2	1	2	2	VAR	2	VAR	...	2	VAR
Standard WUSB Header Fields	bNumblso Segments	wPresentation Time	wLength1	Isoch Data 1	wLength 2	Isoch Data 2		wLength N	Isoch Data N
			wPresentationTime		wPresentationTime + bInterval		wPresentationTime + (n-1)*bInterval		

General Isochronous Data Header

A Data Segment Can Not Be Split Across Packets

Interval and Maximum Packet Size in Descriptors



- Endpoint Descriptor
 - wMaxPacketSize – Maximum size for an isochronous data segment
 - bInterval – Interval between isochronous data segments
- Endpoint Companion Descriptor
 - wOverTheAirPacketSize – Maximum size of over the air packets (one or more isochronous segments)
 - bOverTheAirInterval – Over the air requested service interval

General Presentation Time Use



- Isochronous OUT
 - Host System Applies Presentation Times
 - Presentation Times Indicate Wireless USB Channel Time for Intended Data Consumption
 - Times Are Applied to Make Optimal Use of Device Buffering
 - Device Consumes Based on Presentation Time
 - Host Controller Discards Packets if Wireless USB Channel Time Exceeds Presentation Time and Notifies Device
- Isochronous IN
 - Device Applies Presentation Times
 - Presentation Times Indicate Wireless USB Channel Time When Data Was Produced
 - Device Discards Packets Only When Physical Storage Is Exceeded
 - Host System Manages When Applications Start Consumption to Make Optimal Use of Device Buffering

Presentation Time Standardized for Legacy Application, DWA Support

Isochronous Header and DWA

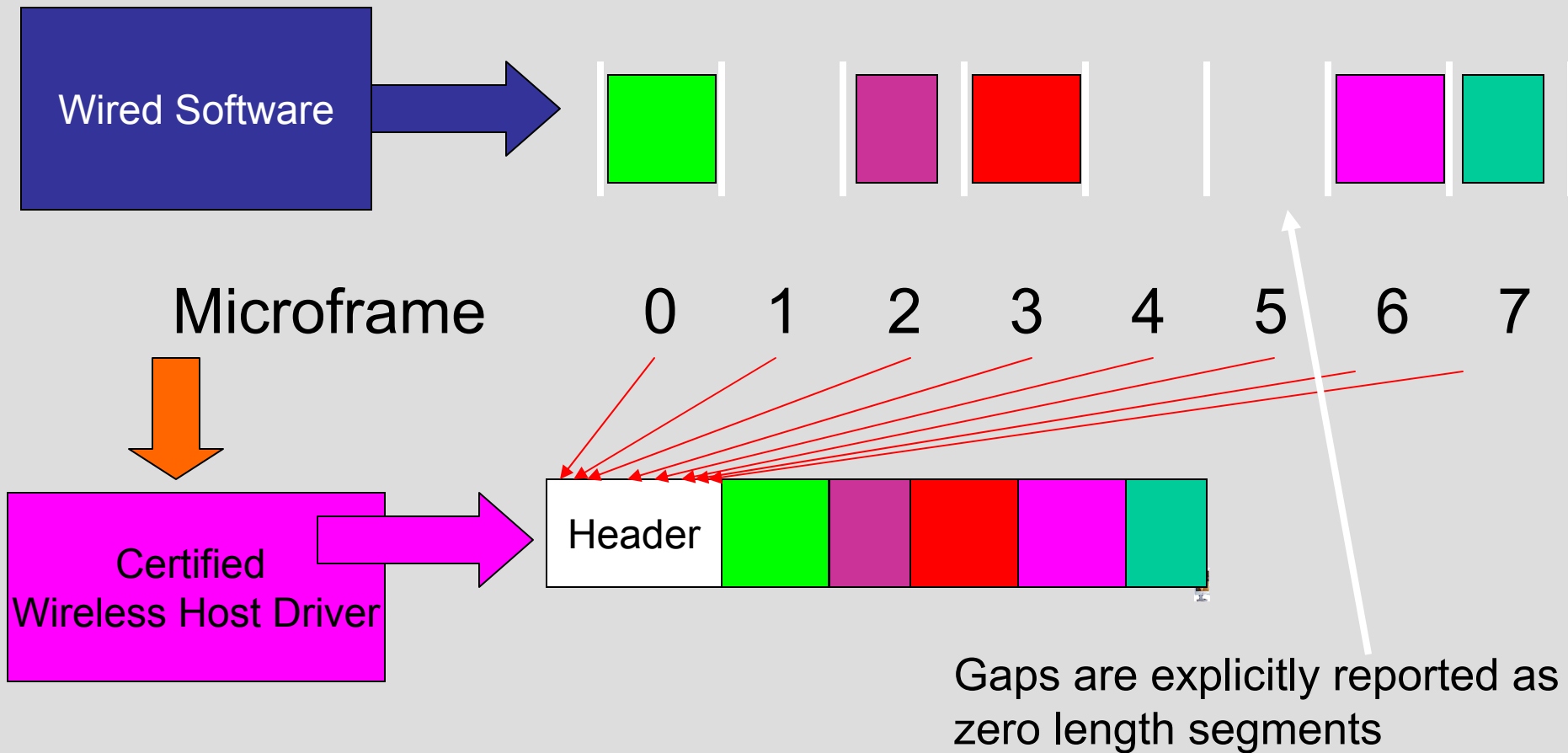


2	1	2	2	VAR	2	VAR	...
Standard CWUSB Header Fields	bNumberIso Segments	MicroframeX	wLength1	Data To Send In Microframe X	wLength2	Data To Send In Microframe X + bInterval	

Not counted towards maxpacket size

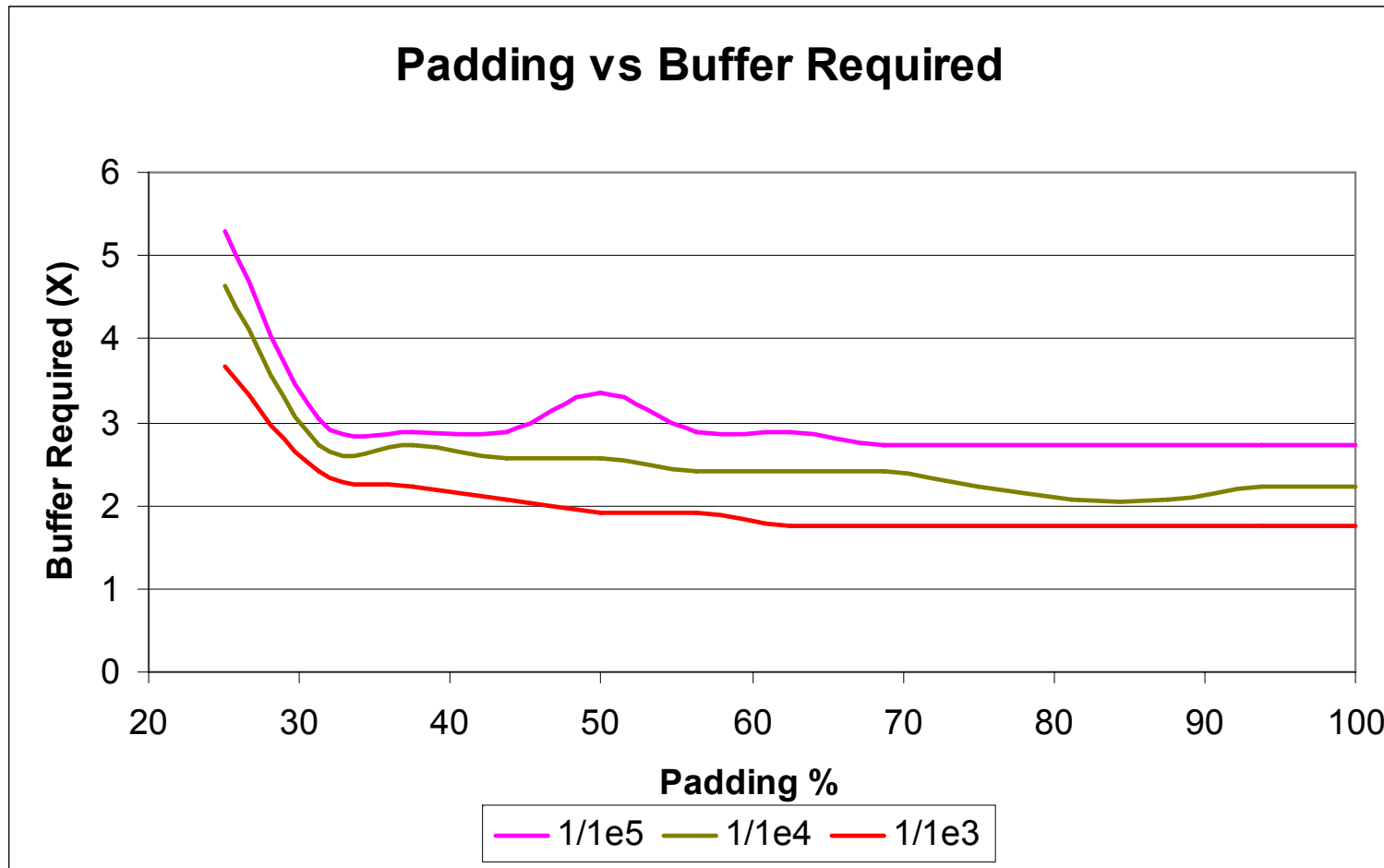
General Isochronous Data Header Can Be Used For DWA Support With Existing Applications and Class Drivers

Isochronous Header – Wired Applications and Class Drivers



Microframe Level Delivery Information Can Be Conveyed To A Native Wireless Device If Necessary. Possible Support For Legacy Apps/Class Drivers With Native Devices

Benefit from Padding Reservation Size for Retries



Short Term Error Tolerance Gains From Reservation Padding Diminish Beyond 30-40 %

Buffer Requirements



- **Device Tradeoff**
 - Acceptable Stream Delay/Latency
 - Cost
 - Short Term Error Tolerance
- **Minimum Buffering**
 - 2x Smallest Guaranteed Service Interval
 - $2 \times 4^* = \sim 8$ milliseconds
 - At least 16 milliseconds recommended
- **Maximum Buffering**
 - Limited by Cost or Acceptable Latency
 - Different Buffer Options Can Be Presented Through Alternate Interfaces

Reporting Buffer Size



4	<i>wMaxStreamDelay</i>	2	Number	<p>For isochronous endpoints this field is a value from 1 to 85535 indicating the maximum amount of delay in 128 microsecond units that can be supported by the stream. The endpoint must provide exactly the amount of buffering to support this delay. An IN endpoint must be able to store this amount of data before having to discard data. An OUT endpoint must be able to fill its buffering (except for storage for less than a maximum size burst) before it is allowed to NAK.</p> <p>Refer to the dataflow Section 4.11 for more information.</p> <p>For interrupt, bulk, and control endpoints this field is reserved and must be zero.</p>
---	------------------------	---	--------	---

- An isochronous OUT endpoint is not allowed to NAK until its buffer is full (less than 1 max burst available)

Reservations



- Endpoint Asks for Actual (Average) Throughput Need without Padding
 - Service Interval (4* ms, 8 ms , 12 ms, . . .)
 - Maximum Burst Size (16)
 - Maximum Packet Size (3584)
- Host System Provides Reserved Time for Retries
 - 30% Minimum
 - If This Can't Be Met Device Is Not Admitted
 - Reserved Pool Size Does Not Grow Linearly with Multiple Streams
 - Host Policy Can Reserve More in Poor Channel Conditions

Reservation Limits



Maximum Burst Size	Maximum Packet Size	Total Payload Per Service Interval
1	1-3584	1-3584
2	257-3584	513-7168
3	342-3584	1025-10752
4	385-3584	1537-14336
5	410-3584	2049-17920
6	427-3584	2561-21504
7	439-3120	3073-21845
8	449-2730	3585-21845
...		
16	481-1365	7681-21845

Average bandwidth limited to 40 mbps to meet regulatory concerns







Reservations – Admission Decisions

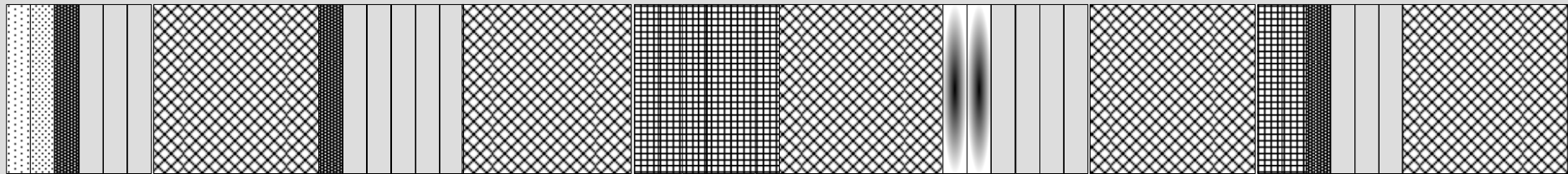


- Set Interface Call Occurs
 - Previous Communication with Device May Only Have Occurred at Base Rate
 - Admission Decisions Depend on Highest Usable Rate
 - Host Needs a Standard Mechanism to Gather Additional Information for Admission Decision
- Required Loopback Commands
 - DATA_LOOPBACK_WRITE
 - DATA_LOOPBACK_READ
 - Standard Commands Required on Control Pipe
 - Data Phase Can Occur at Any Supported Rate
 - Will Also Be Used in Testing/Enabling/Compliance

Flow Control



-  Can Be Reclaimed
-  Valid Response
-  NAK
-  Smashed Packet
-  No Device Response
-  Not Reserved For Periodic Endpoint



Interval 1

Interval 2

Interval 3

Interval 4

Interval 5

Isochronous IN Error Conditions – Device Buffer Perspective



Example

- 100 Packets Per Interval
- 3 Intervals of Buffering (300 Packets)
- 120 Chances Scheduled Per Interval (20% Padding)

300 Packet Buffer

Stays Empty With Good Link

Error Conditions – Device Buffer Perspective



Example

- Error Rate Jumps to 20%
- 96 Packets Transferred Per Interval
- 4 Packets Added to Device Buffer Per Interval
- It Will Take 75 Intervals for Buffer to Overflow (Average)

75 Interval Buffer

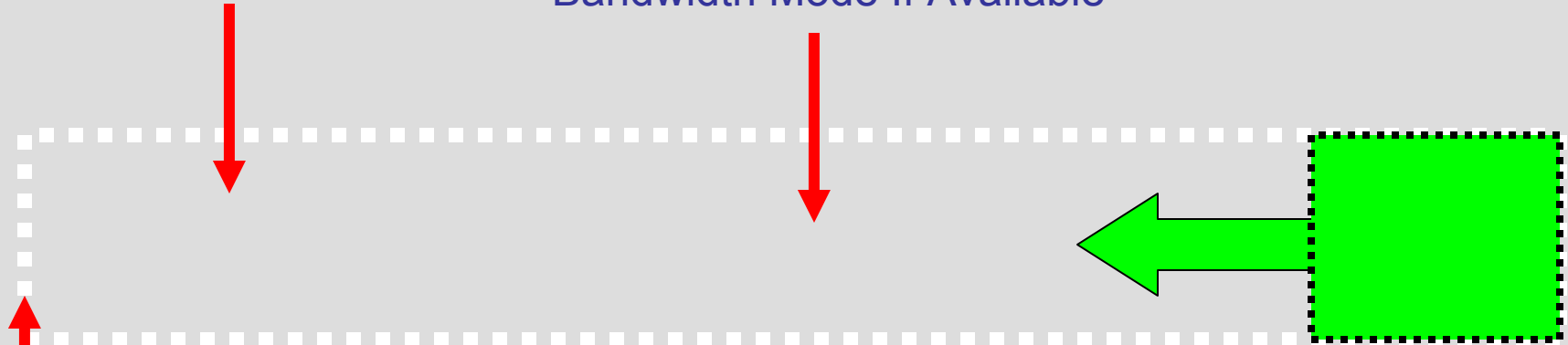
A diagram showing a large rectangular area defined by a dotted black border. The text "75 Interval Buffer" is centered within this area. On the right side of the dotted border, there is a vertical bar of bright green color, representing the buffer's capacity or a specific state.

General Error Handling (Device Buffer)



Other Adjustments (Data Rate, TX Power etc)

Switch to Alternate Bandwidth Mode If Available



Buffer Empty. Standard Error Reporting And Recovery
-Restart Stream
-Continue

Maximum Packet Size Adjustment

Reservation Increase If Possible. Host Can Temporarily Use Bulk Reserved Time, etc.

Data Discard Details



- Isoch OUT
 - Isoch Out – Host Discards If Presentation Time Expires
 - Isoch Out – MMC IE Indicates Discard and Burst Sequence Skip
- Isoch IN
 - Isoch In – Device Discards Due to Physical Storage Limits
 - Discard Removes Packet and Replaces It with New Packet Using the Same Burst Sequence Number, etc
 - Requires Host Receivers to “Order” Based on Presentation Time

1.0 Spec defines ISOCH_DISACRD_IE to provide explicit information to devices in Isoch OUT discard cases.

Isochronous Packet Discard IE



Offset	Field	Size	Value	Description									
0	<i>bLength</i>	1	Constant	The size of this IE: 14 bytes									
1	<i>IE_Identifier</i>	1	Constant	WISOCH_DISCARD_IE									
2	<i>bDiscardID</i>	1	Number	An ID number for the discard IE									
3	<i>bDeviceAddress</i>	1	Number	Device Address									
4	<i>bmAttributes</i>	1	Bitmap	<p>This bitmap has the following encoding</p> <table border="1"> <thead> <tr> <th>Bit</th> <th>Value</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>3:0</td> <td>Variable</td> <td>USB Endpoint Number</td> </tr> <tr> <td>7:4</td> <td>Zero</td> <td>Reserved</td> </tr> </tbody> </table>	Bit	Value	Description	3:0	Variable	USB Endpoint Number	7:4	Zero	Reserved
Bit	Value	Description											
3:0	Variable	USB Endpoint Number											
7:4	Zero	Reserved											
5	<i>bFirst ReceiveWindow Position</i>	1	Number	The sequence number of the first position in the <i>bmDeviceReceiveWindow</i> field.									
6	<i>wNumber Discarded Packets</i>	2	Number	The number of discarded packets									
8	<i>wNumber Discarded Segments</i>	2	Number	The number of discarded isochronous segments.									
10	<i>bmDevice Receive Window</i>	4	Bitmap	<p>Bitmap indicating the sequence numbers that the host expects to be active in the device receive window.</p> <p>The dataflow chapter explains how the host calculates the expected receive window when discards occur.</p>									

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Interrupt Endpoints



- Regular and low power versions
- Retry guarantee
 - Regular 5
 - Low Power 2
- Service Interval
 - 4* milliseconds smallest available due to WUSB Channel characteristics
- Max Burst Size Is 1
- Maximum Packet Sizes
 - Regular – 1024
 - Low Power – 64
- Flow Control Has Same Meaning as Isochronous
 - Regular – Must NAK
 - Low Power – Allowed Not to NAK (but must periodically to avoid trust timeouts)



Summary and Conclusions

- Wired Iso Model Doesn't Work for Wireless
 - No Retries
 - Small Service Intervals
 - No Chance to Recover if Data Isn't Sent in Specified Interval
- Wireless Media Problems
 - Much Higher Error Rates Than Wired
 - Much Larger Service Interval Bounds
- Key Iso Model Changes
 - Retries and Handshaking
 - Delay Added to Allow Service Chances in Multiple Intervals
 - More Efficient Use of Bandwidth
 - Better Short Term Error Tolerance
 - More Time to React When Link Degradation Persists
 - Data Header with Presentation Time Information
 - Potential Legacy Class/Application Software Support
 - DWA Support



Developers Conference 2006

Taipei, Taiwan



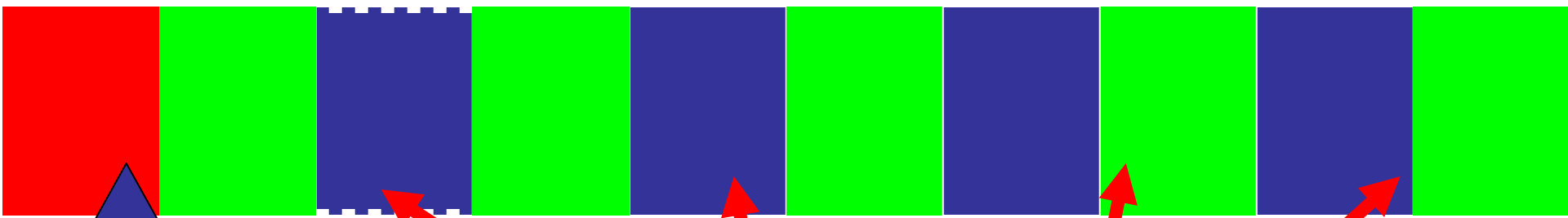
Backup Simulation Model and Results



Simulation Model

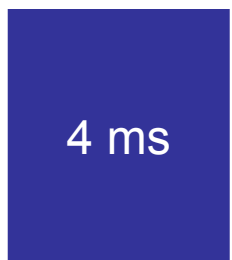
- Parameters
 - Superframe Layout
 - Buffer Size
 - Retry Count
 - PER
 - Packet Size
 - Reservation Padding
- Simulations Results

Superframe Layout



Worst Case Beacon (4 ms)

CWUSB Host Time

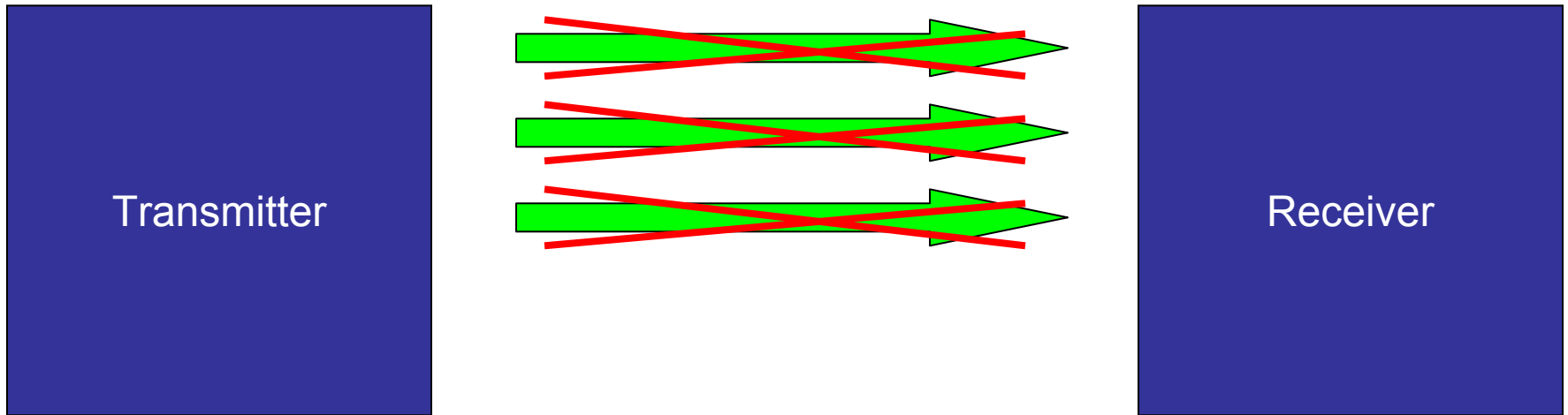


CWUSB Host Reservation



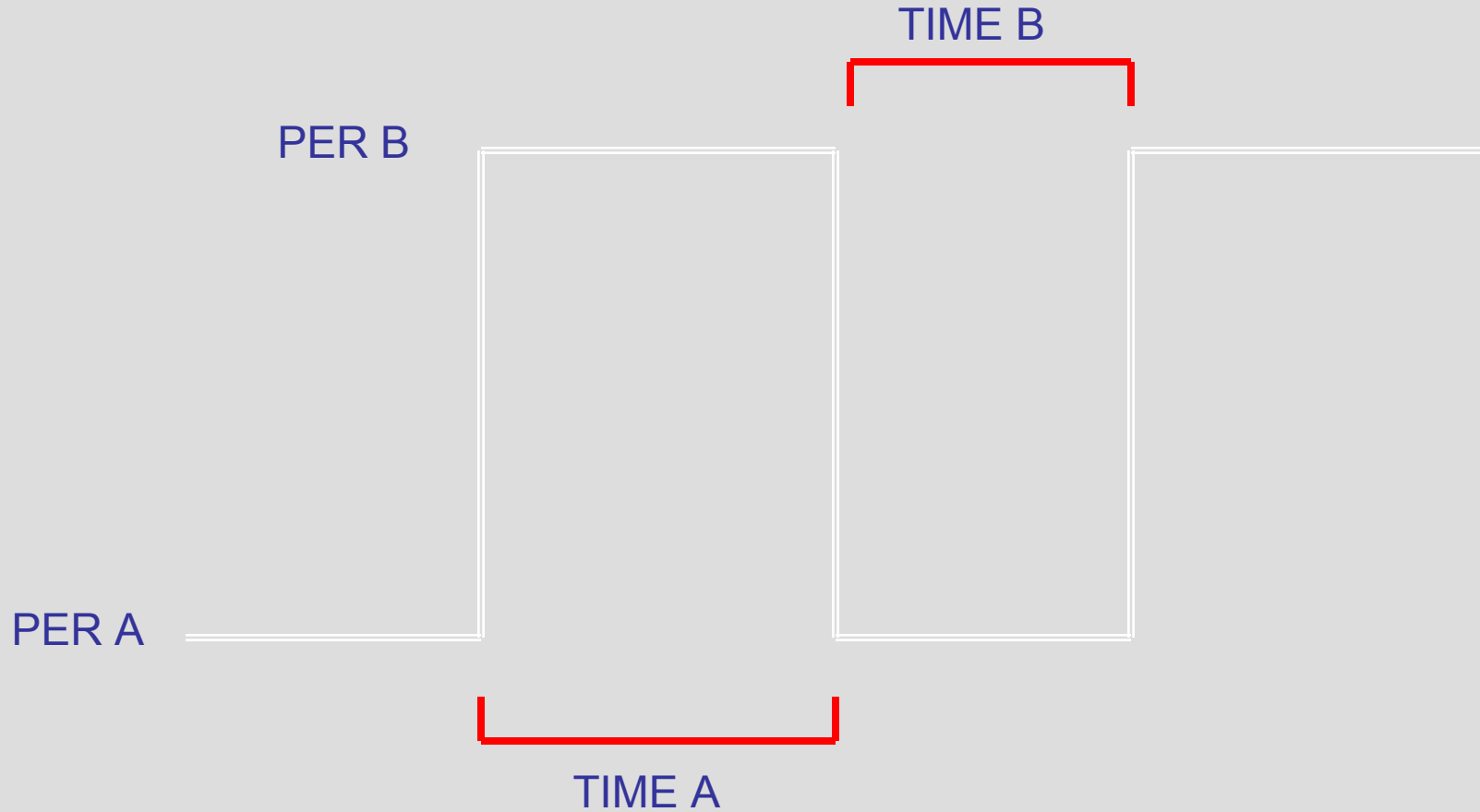
Other Reservation

Retry Count

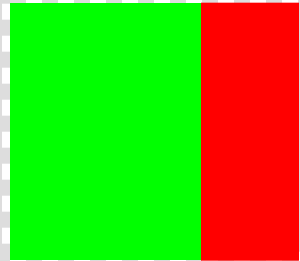


How Many Times Can a Packet Fail Before You Give Up and Move onto the Next Packet

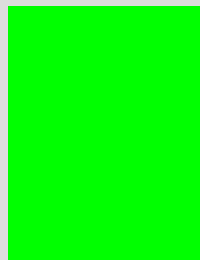
Packet Error Rate



Reservation Padding



CWUSB Host Time Slot



Reservation Size If
PER Is Zero



Padding For
Retries

Simulations



- Vary One Parameter at a Time
 - Reservation Padding
 - 10%, 20%, 30%, 40%
 - PER
 - Glitch Height, Width and Spacing
 - Buffer Size
 - 2x, 4x, 6x . . .
 - Retry Count
 - None, 2-7
 - Reservation Spacing
 - One Chunk vs Spread Out In Several Pieces

8 ms Buffer



Error Rate	Glitch Error Rate	Drop (Buffer)	Drop (Retry Count)
2	0	71	0
4	0	128	0
6	0	404	0
8	0	582	0
10	0	951	0
10	10	858	0
10	20	1213	0
10	30	1194	0
10	40	1402	0
10	50	1891	5
10	60	2517	19
10	80	4396	202
10	100	7813	1103

16 ms Buffer



Error Rate	Glitch Error Rate	Drop (Buffer)	Drop (Retry Count)
2	0	0	0
4	0	0	0
6	0	0	0
8	0	0	0
10	0	2	0
10	10	1	0
10	20	0	0
10	30	0	0
10	40	0	0
10	50	1	4
10	60	8	23
10	80	34	212
10	100	58	1148

24 ms Buffer



Error Rate	Glitch Error Rate	Drop (Buffer)	Drop (Retry Count)
2	0	0	0
4	0	0	0
6	0	0	0
8	0	0	0
10	0	0	0
10	10	0	0
10	20	0	0
10	30	0	0
10	40	0	0
10	50	0	7
10	60	0	11
10	80	0	214
10	100	0	1148

24 ms – Various Retry Counts



Glitch Error Rate	Max Retry Limit	Drop (Retry)	Drop (Buffer)
40	3	73	0
40	5	12	0
40	7	1	0
60	3	301	0
60	5	69	0
60	7	22	0
80	3	932	0
80	5	408	0
80	7	194	0
100	3	2057	0
100	5	1115	0
100	7	1148	0