Gap Count Determination through PHY Pinging

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1.0 Background

The 1394–1995 specification suggests maximum cable lengths of 4.5m. Annex E lists gap counts to use for given topology sizes assuming this maximum cable length. If longer cables are to be used, the bus manager can not assume 4.5m cables. A more general method of finding the propagation delays is needed. Bill Duckwall has proposed "Phy pinging." Using this method the bus manager sends a Phy ping packet to a node and that node's PHY responds with a self–ID packet. The bus manager times this subaction to measure the cable and phy delays between itself and the target node. Jerry Hauck has proposed that to reduce the hardware required the timer can be implemented in bus manager capable links. Although every Phy needs the ability to respond to ping requests, only bus manager capable links need the timer. This paper is to propose a method for using the Phy pinging to determine the gap count.

2.0 Definition of Terms

To keep the sizes down, some of the names in this paper are just shortened versions of the 1394–1995 names. Some of the equations are derived later in this paper. Other terms are new and are being proposed for inclusion in P1394A. The subscripts BM, A, B, and C in this paper refer to the Bus Manager and nodes A, B, and C respectively.

TERM	MEANING	VALUE	NEEDS TO BE DEFINED, SUGGESTED VALUE
ArbDelMax	Maximum arb_delay	GC*4/BRMin	
ArbResetGapMin	Minimum generated Arb reset gap	(51 + GC * 32)/BRMax	
ArbRespDel			PD
BRMax	Maximum BASE_RATE	98.314Mbit/S	
BRMin	Minimum BASE_RATE	98.294Mbit/S	
CD	Cable Delay	Max 5.05nS/m * length	
DE	DATA_END_TIME	0.24uS to 0.26uS	
GC	Gap Count	((BRMin)(BRMax)(RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$) – 51BRMin + 29BRMax)/(32BRMin – 20BRMax)	
Hops	Cable hops between nodes		
JPD	Jitter in PHY Delay		20 nS (1 SClk period)
LinkToPhyDel	Link to PHY Delay		40 nS – 62 nS
MeasError	Phy Ping Measurement Error	Max 20 nS	
PD	PHY Delay	max 144 nS	min 33.3 nS
PDDeltaMin		$PDMin_{BMA}$ + $PDMin_{BMB}$ – $PDMax_{AB}$	
PhyToLinkDel	PHY to Link Delay		81 nS – 102 nS (8/BRMax – 10/BRMin
PingMeas	Measured round trip time between a node and the Bus Manager	DE + $LinkToPhyDel_{BM}$ + 2((hops–1)(CD + PD)) + 2CD + ArbRespDel + PingRespTime + $PhyToLinkDel_{BM}$ + MeasError	
PingRespTime	PHY Ping Response Time		122 nS – 143 nS (12/BRMax – 14/BRMin)
PropMax	Calculated maximum round trip time between a node and the Bus	PingMeas – DEMin – $LinkToPhyDelMin_{BM}$ + 2((hops–	

	Manager	1)(JPD)) – ArbRespDelMin – PingRespTimeMin – $PhyToLinkDelMin_{BM}$	
PropMin	Calculated minimum round trip time between a node and the Bus Manager	PingMeas – DEMax – $LinkToPhyDelMax_{BM}$ – 2((hops–1)(JPD)) – ArbRespDelMax – PingRespTimeMax – $PhyToLinkDelMax_{BM}$	
RTDel	Round Trip Delay	2(hops–1)(CD+PD) +2CD	
SubactionGapMax	Maximum Observed Subaction Gap	(29 + 16GC)/BRMin + ArbDelMax + RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$	

3.0 Gap Count as a function of Maximum Round Trip Delay

Define the Round Trip delay to include round trip cable and phy propagation delays.

1) RTDel = 2(hops–1)(CD+PD) +2CD

To insure that no node sees an arb reset gap before another node sees a subaction gap, Gap Count must be set such that

2) ArbResetGapMin > SubactionGapMax

The minimum detection time for arb reset gap is

3) ArbResetGapMin = (51 + 32GC)/BRMax

The observed subaction gap is the time between an ack and the arrival of arbitration signals. The subaction gap is largest at the node which sent the ack. The maximum observed subaction gap occurs when the node sending the gap and the node sending the arbitration signals are at opposite ends of the path with the longest propagation delays.

4) SubactionGapMax = (29 + 16GC)/BRMin + ArbDelMax + RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$

5) ArbDelMax = 4GC/BRMin

So for the smallest usable gap count,

(51 + 32GC)/BRMax = (29 + 16GC)/BRMin + ArbDelMax + RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$

51BRMin + 32BRMin(GC) = 29BRMax + 16BRMax(GC) + 4BRMax(GC) + (BRMin)(BRMax)(RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$)

GC(32BRMin – 20BRMax) = (BRMin)(BRMax)(RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$) –51BRMin + 29BRMax

6) GC = ((BRMin)(BRMax)(RTDelMax + $ArbRespDelMax_A$ + $ArbRespDelMax_B$) – 51BRMin + 29BRMax)/(32BRMin – 20BRMax)

The gap count must be the next larger integer.

4.0 Determination of Maximum Round Trip Delay

The path with the longest delay is the one which determines the gap count. Since the actual PHY delays and cable delays are unknown, each leaf to leaf path must be checked and the worst one used. The longest delay is not necessarily in the path with the most nodes.

The time measured by PHY pinging from the Bus Manager to another node includes the data end of the PHY ping request, the delays through the Bus Manager link, the cable and phy propagation delays in both directions, the target arbitration response delay, the PHY Ping response time and measurement error. This equation is for the simplest case when all the cable and phy delays are the same and can be multiplied by the number of hops. In some cases the cable and phy delays may be different through different nodes and the terms may need to be separated.

7) $PingMeas = DE + LinkToPhyDel_{BM} + 2((hops–1)(CD + PD)) + 2CD + ArbRespDel + PingRespTime + PhyToLinkDel_{BM} + MeasError$

The calculated maximum propagation time is the measured time plus uncertainties with the minimums of the undesired terms subtracted out.

8) $PropMax = PingMeas – DEMin – LinkToPhyDelMin_{BM} + 2((hops–1)(JPD)) – ArbRespDelMin – PingRespTimeMin – PhyToLinkDelMin_{BM}$

The calculated minimum propagation time is the measured time minus uncertainties with the maximums of the undesired terms subtracted out.

9) $PropMin = PingMeas – DEMax – LinkToPhyDelMax_{BM} – 2((hops–1)(JPD)) – ArbRespDelMax – PingRespTimeMax – PhyToLinkDelMax_{BM}$

The Phy delay jitter, JPD terms in the equations for PropMax and PropMin might be eliminated if paths are pinged multiple times and statistical analysis is used to determine the average and maximum round trip delays. By pinging the same path multiple times, the average Ping Measurement and standard deviation could be determined. A safe maximum for PingMeas could be used and the terms 2((hops-1)(JPD)) could be removed as the Phy delay jitter would be accounted for through the statistical methods in the maximum PingMeas term. This would help to find smaller maximum values and larger minimum values and result in the selection of a more optimal gap count. Without the statistical methods, the results would typically be an average ping measurement adjusted by the full phy delay jitter terms which would yield a value outside the actual range of measurements.

There are three distinct scenarios when PHY Pinging.

4.1 Bus Manager Leaf to Leaf

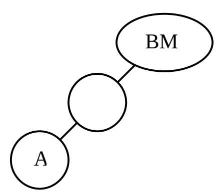

Figure 4-1 – Bus Manager Leaf to Leaf

The maximum round trip time from bus manager to A is just the calculated maximum propagation time for A.

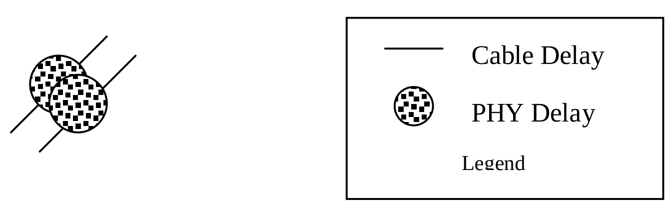

Figure 4-2 – Graphical representation of Round Trip Delay for Bus Manager to Leaf

10) $RTDelMax = PropMax_A$

4.2 Leaf to Leaf through Bus Manager

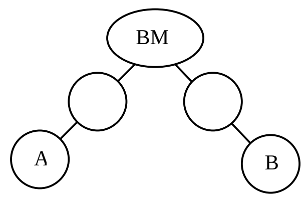

Figure 4-3 – Leaf to Leaf through Bus Manager

The maximum round trip time from A to B is the calculated maximum propagation time to A plus the calculated maximum propagation time to B plus twice the maximum bus manager PHY delay.

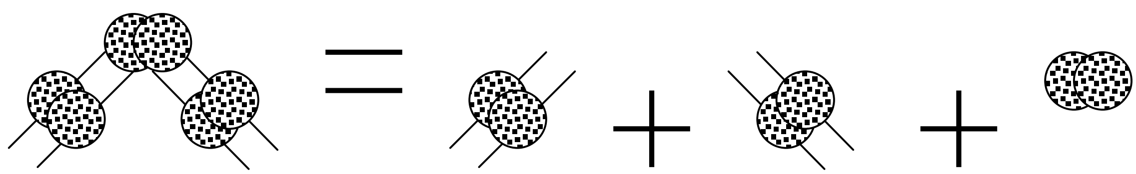

Figure 3-4 – Graphical Representation of Equation for Round Trip Delay for Leaf to Leaf through Bus Manager

11) $RTDelMax = PropMax_A + PropMax_B + 2PDMax_{BM}$

4.3 Leaf to Leaf not through Bus Manager

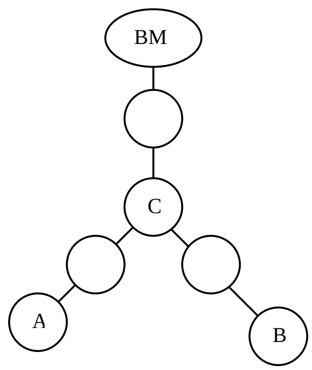

Figure 4-5 – Leaf to Leaf not through Bus Manager

When pinging from Bus Manager to nodes A and B, the Phy delays seen through node C are along the paths between the port leading to the Bus Manager and the ports leading to nodes A and B. However, the Phy delay of interest is the one between the child ports along the path from node A to node B. Define the Phy Delay Delta as the difference between the sum of the port to port paths between Bus Manager and A and B minus the port to port path between nodes A and B. This value may be different in nodes which have 1394B ports than in 1394A nodes.

12) PDDeltaMin = $PDMin_{BMA} + PDMin_{BMB} - PDMax_{AB}$

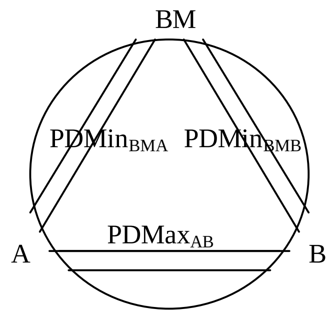

Figure 4-7 – Phy Delays along paths through a node

The maximum round trip time from A to B is the calculated maximum propagation time from bus manager to A plus the calculated maximum propagation time from bus manager to B minus twice the calculated minimum propagation time from bus manager to C minus twice node C's minimum PHY delay minus twice the minimum Phy Delay Delta for node C.

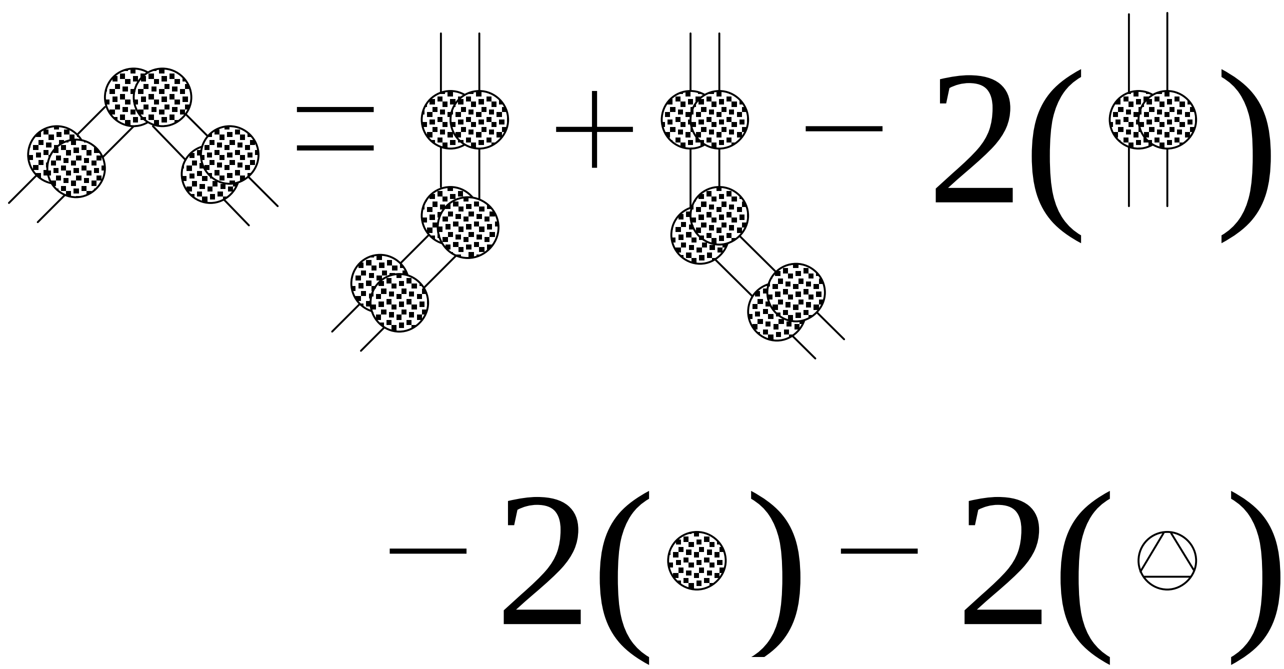

Figure 4-7 – Graphical representation of Equation for Round Trip Delay for Leaf to Leaf not through Bus Manager

13) RTDelMax = $PropMax_A + PropMax_B - 2(PropMin_C) - 2(PDMin_C) - 2(PDDeltaMin_C)$

5.0 Example

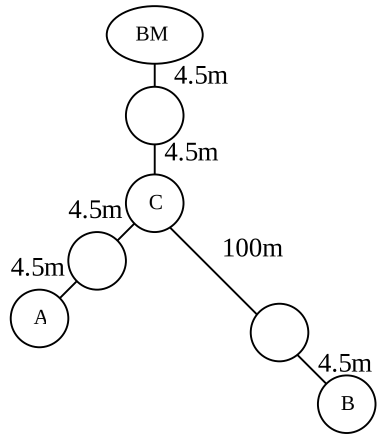

Figure 5-1 – Leaf to Leaf not through Bus Manager

In this example, the bus manager must ping all the other leaf nodes, A and B. It must then calculate the maximum round trip delay for all leaf to leaf paths, BM to A, BM to B, A to B. The biggest round trip delay is used to calculate the gap count.

5.1 Phy Ping Measurements

Assuming the following actual values:

Term	Actual Value
DE	250nS
$LinkToPhyDel_{BM}$	51nS
CD	5.05nS/M * length
PD	100nS
$ArbRespDel_A$	100nS
PingRespTime	132nS
$PhyToLinkDel_{BM}$	92nS
MeasError	10nS

Then the measured round trip time to nodes A, B and C from the bus manager are

$PingMeas_A = DE + LinkToPhyDel_{BM} + 2((Hops - 1)(CD+PD)) + 2*CD + ArbRespDel_A + PingRespTime_A + PhyToLinkDel_{BM} + MeasError$
= 250nS + 51nS + 8 * 5.05nS/M * 4.5M + 6 * 100nS + 100nS + 132nS + 92nS + 10nS
= 1417nS

$PingMeas_B = DE + LinkToPhyDel_{BM} + 2((Hops - 1)(CD+PD)) + 2*CD + ArbRespDel_B + PingRespTime_B + PhyToLinkDel_{BM} + MeasError$
= 250nS + 51nS + 6 * 5.05nS/M * 4.5M + 2 * 5.05nS/M * 100m + 6 * 100nS + 100nS + 132nS + 92nS + 10nS
= 2381nS

$PingMeas_C = DE + LinkToPhyDel_{BM} + 2((Hops - 1)(CD+PD)) + 2*CD + ArbRespDel_C + PingRespTime_C + PhyToLinkDel_{BM} + MeasError$
= 250nS + 51nS + 4 * 5.05nS/M * 4.5M + 2 * 100nS + 100nS + 132nS + 92nS + 10nS
= 926nS

5.2 Maximum and Minimum Progagation Delay Calculations

The following equations do not assume the use of statistical methods to eliminate the Phy delay jitter terms. Results may be improved if nodes are pinged repeatedly and statistical methods are used.

$PropMax_A$=$PingMeas_A$–DEMin–$LinkToPhyDelMin_{BM}$+2((hops–1)(JPD))–ArbRespDelMin–PingRespTimeMin–$PhyToLinkDelMin_{BM}$
= 1417nS – 240nS – 40nS + 6 * 20nS – 33.3nS – 122nS – 81nS
= 1021nS

$PropMax_B$=$PingMeas_B$–DEMin–$LinkToPhyDelMin_{BM}$+2((hops–1)(JPD))–ArbRespDelMin–PingRespTimeMin–$PhyToLinkDelMin_{BM}$
= 2381nS – 240nS – 40nS + 6 * 20nS – 33.3nS – 122nS – 81nS
= 1985nS

$PropMin_C$=$PingMeas_C$–DEMax–$LinkToPhyDelMax_{BM}$–2((hops–1)(JPD))–ArbRespDelMax–PingRespTimeMax–$PhyToLinkDelMax_{BM}$
= 926 – 260nS – 61nS – 2 * 20nS – 144nS – 142nS – 102nS
= 177nS

5.3 Maximum Round Trip Time Calculations

$RTDelMax_{BMA}$ = $PropMax_A$
= 1021nS

$RTDelMax_{BMB}$ = $PropMax_B$
= 1985nS

PDDeltaMin = $PDMin_{BMA}$ + $PDMin_{BMB}$ – $PDMax_{AB}$
= 33.3nS + 33.3nS – 144nS
= –77.4nS

$RTDelMax_{AB}$ = $PropMax_A$ + $PropMax_B$ – 2($PropMin_C$) – 2($PDMin_C$) – 2($PDDeltaMin_C$)
= 1021nS + 1985nS – 2(177nS) – 2(33.3nS) – 2(–77.4nS)
= 2740nS

5.4 Gap Count Calculation

The largest round trip delay calculated for any leaf to leaf path is 2740nS for node A to node B. Gap count is calculated using this value.

GC = ((BRMin)(BRMax)($RTDelMax_{AB}$ + $ArbRespDelMax_A$ + $ArbRespDelMax_B$) – 51BRMin + 29BRMax)/(32BRMin – 20BRMax)
= ((98.294)(98.314)(2.74uS + 0.144uS + 0.144uS) – 51(98.294) + 29*(98.314))/(32(98.294)–20*(98.314))
= 22.98

The gap count in this example must be set to 23 to guarantee node A never sees an arbitration reset gap before node B sees a subaction gap.

6.0 Issues

If PHY pinging is done at S100, is this the worst case delay? PHY delays at higher speeds must not be greater than the PHY delay at S100 for this to work. This is probably true for S100, S200, S400. S800 and above will probably operate in Beta mode and pinging should still accurately measure the propagation delays.

Should values needing definition be specified or queried? LinkToPhyDel and PhyToLinkDel may need to be specified anyway to set timing requirements for link arbitration requests. Can gap count be done purely by querying the Phys?

Are 1394B Phys or subPhys required for longer cables?