

Deploying a Packet Based Bidirectional TDD Telemetry Link System

Ray O'Connell¹ Sean Wilson²,

RoboCom Technologies ¹, Quasonix ²

Cincinnati, Ohio

ray@robocomai.com

swilson@quasonix.com

ABSTRACT

Conversion of telemetry links to packet-based Ethernet communications is underway with both unidirectional and bi-direction links being deployed. For both test range and other applications, the user community has embraced the simplicity of bridging Ethernet test article and ground networks. With bidirectional packet based solutions, the adaptation of existing telemetry physical layer systems is often preferred. Most of these applications use Frequency Division Duplex (FDD) as long as co-site interference can be mitigated and two frequencies are obtained. A Time Division Duplex (TDD) solution requires only a single frequency and has no co-site bidirectional inter-link interference. The TDD approach requires some amount of design effort by the communications hardware provider to convert to a switched based system, though once done the benefits over FDD are realized by the end user. A deployed TDD bidirectional Ethernet system is presented and changes to the streaming telemetry system.

INTRODUCTION

Bidirectional packet based telemetry communications systems using parallel transmission paths currently available [1]. The advantage of using a single frequency with time division duplex operation has been discussed though had not be adapted to existing production ready streaming telemetry systems. This paper discusses a new type of telemetry system capability which uses production streaming telemetry components which have undergone system firmware updates to provide a bidirectional system operating on a single frequency. The first part of this paper will show what this switched telemetry system architecture looks like. This is followed by a component breakdown for the ground and airborne sides. The next section covers system status monitoring and system configuration. This is followed by a test results as the production system components were integrated for verification prior to customer use.

CHAPTER 1 - TDD SYSTEM ARCHITECTURE

The building of a TDD capable system [2] based on an existing streaming telemetry solution involved updates to four existing components in the current non-switched system: Transmitter, Receiver, Tracking Antenna and EVTMM Ethernet Encoder/Decoder. This updated system then provided the packet-based switched streaming telemetry system represented in the following figure.

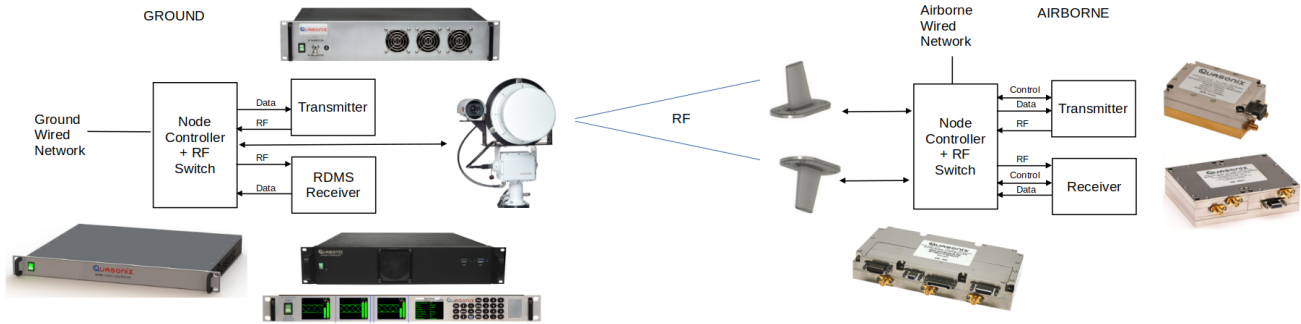


Figure 1 – Deployable Range Telemetry Bi-Directional Time Division Duplex System

A wide range of channel configurations are possible depending on the system components that are selected. The new system supports new TDD switch telemetry modes as well as support for legacy FDD modes supported by the previous EVTMM encoder / decoder based systems [3]. Support for all current modulation, LDPC coding and data rates of the current streaming telemetry systems is maintained. The following table shows a summary of the high-level changes to the production telemetry communications devices as a result of the integration of TDD functionality.

Component	Change
Transmitter	RF switching speed increased
Receiver	Freezing of current acquisition settings under external control Sync word reception to obtain a data quality metric calculation with a duty cycled received signal
Tracking Antenna	Adaption to regular signal outage of received signal during uplink transmissions
Packet Encoder/Decoder Node Controller	A new device was developed which provides the serial-to-packet and packet-to-serial capability of the existing EVTMM encoder/decoder adding the capability for transmit / receive timing control. With the additional processing of the new node controller design additional control and status capabilities were also added.

Table 1 - Summary of Component Modifications for a TDD Capable System

For the production transmitter design new registers were added to control the switching of the transmitter including filtering the transmit/receive digital control line transitions as received from the EVTMM node-controller when in TDD mode. The receiver had more significant modifications which included a freeze state hardware control line holding the receiver state unchanged during transmit mode and resumed at the beginning of the next reception period. To facilitate data quality metric (DQM) acquisition a minimum size synchronization packet is inserted by the EVTMM node-controller at the start of each data period which contains a known pattern processed by the receiver to aid in the generation

of a link quality metric. The tracking antenna receives a transmit-receive state line which directional search algorithm uses during uplink transmission.

The EVTm encoder provides a reliable serialization of user packet data for transmission and also buffering burst of packets from the higher speed wire interface as needed. On the decoder side the packet stream received as serial data from the telemetry receiver is decoded into the original Ethernet packets and retransmitted as packets on the wired interface.

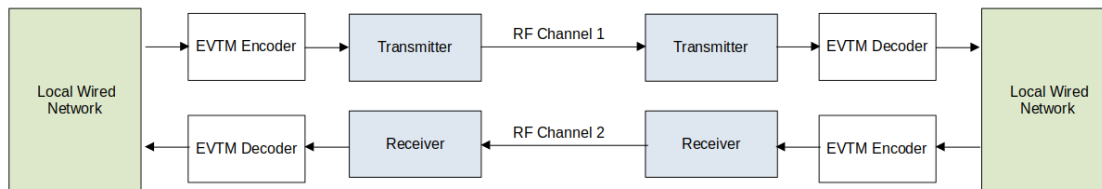


Figure 2 – Existing FDD Non-Switched EVTm System

In the TDD modified EVTm node-controller design in addition to the EVTm encode/decode capability the node controller solution adds timing coordination to set a transmit-receive duty cycle using the transmit window assigned. The EVTm node-controller contains three main functional areas: the EVTm Application Service, EVTm Link Service and high speed FPGA logic and support drivers. The enhanced node-controller design also adds a multiple user interfaces including a command line interface, browser graphical interface and external Application Programming Interface (API).

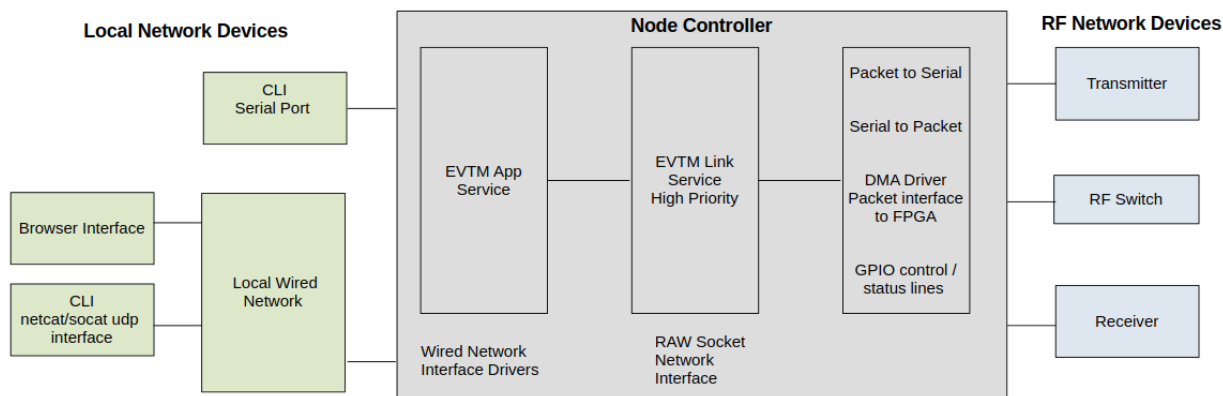


Figure 3 – Updated TDD Capable EVTm Node Controller

CHAPTER 2 - GROUND TDD SUPPORT SYSTEM

The initially deployed TDD ground system solution shown in the following figure, consisted of rack based components and a low gain tracking antenna. Control of the system used existing graphical based user interfaces for the receiver, transmitter and tracking antenna. The EVTm node controller added a new interface which supported control of the TDD uplink / downlink transmit duty cycle as well as the graphical display and logging of local and remote airborne statistics.

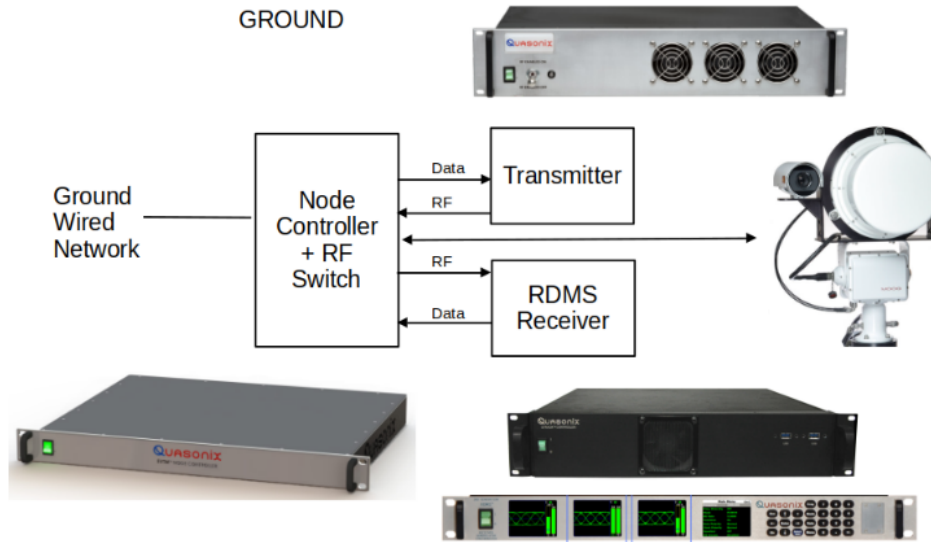


Figure 4 – Ground System Component Breakdown

With the system set to test article timing master mode the ground system remains in receive mode until the uplink transmit message is received on the downlink from the test article [4]. The airborne system continuously transmits the downlink data to the ground system in the downlink transmission window whereas the ground system send uplink data only when enabled by the downlink transmission. The ground receiver RDMS browser window shows the status of the received TDD downlink signal with the EVTm displaying the uplink signal received by the airborne compact receiver. This uplink receiver status data is transmitted by way of packets to the ground EVTm along with other airborne status information.

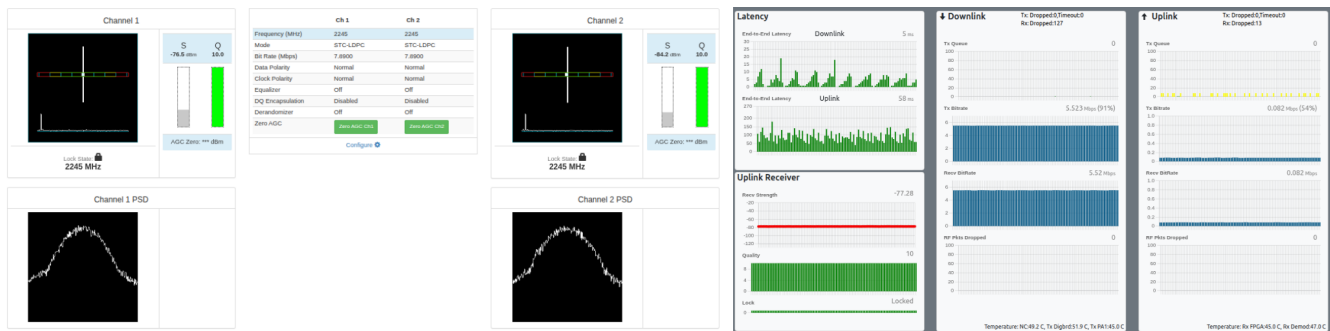


Figure 5 – Ground System Uplink and Downlink Monitoring

CHAPTER 3 - AIRBORNE SYSTEM

The airborne system consist of compact versions of the ground equipment as shown in the figure below. The EVTm node-controller provides a central connection point for both power and control [4]. The same EVTm graphical control and status interface is available at the airborne EVTm along with serial port control. These user interfaces are used in lab and some field testing though are generally not attached once a mission is begun.

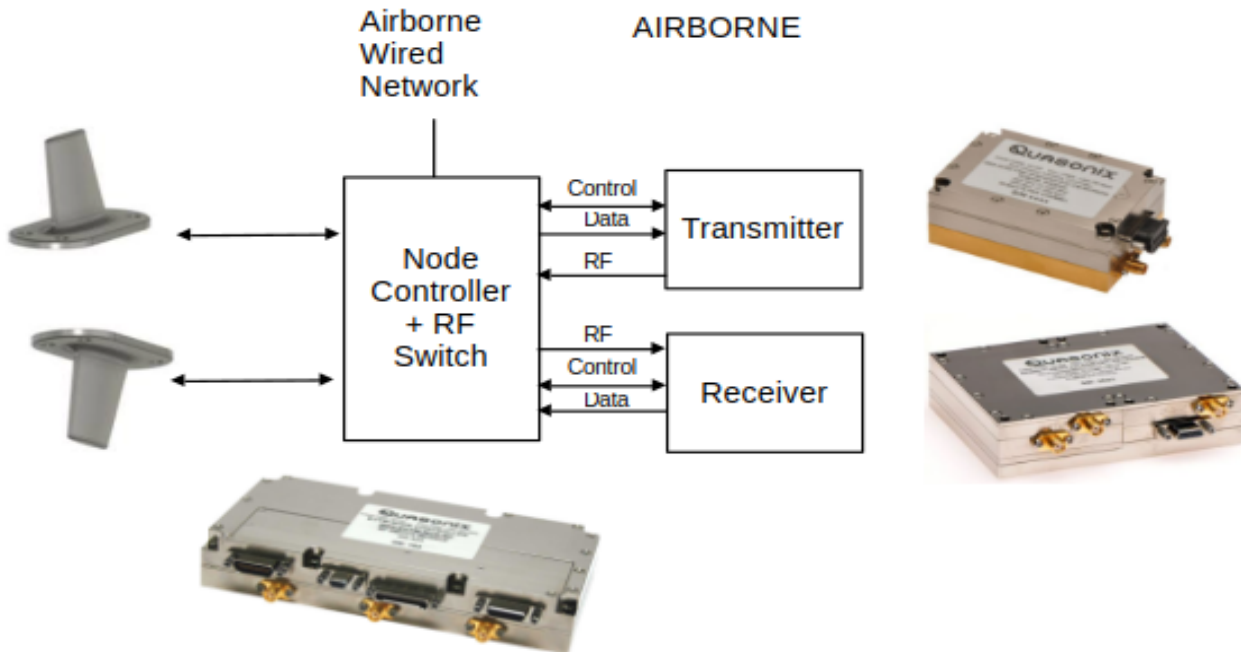


Figure 6 – Airborne System Component Breakdown

The RF-switch which is co-located with the EVTm node-controller provides a central point for RF signals from the receiver and to the transmitter. The receiver, transmitter and EVTm node-controller can be arranged as needed based on power dissipation and space constraints with a side by side arrangement shown here.

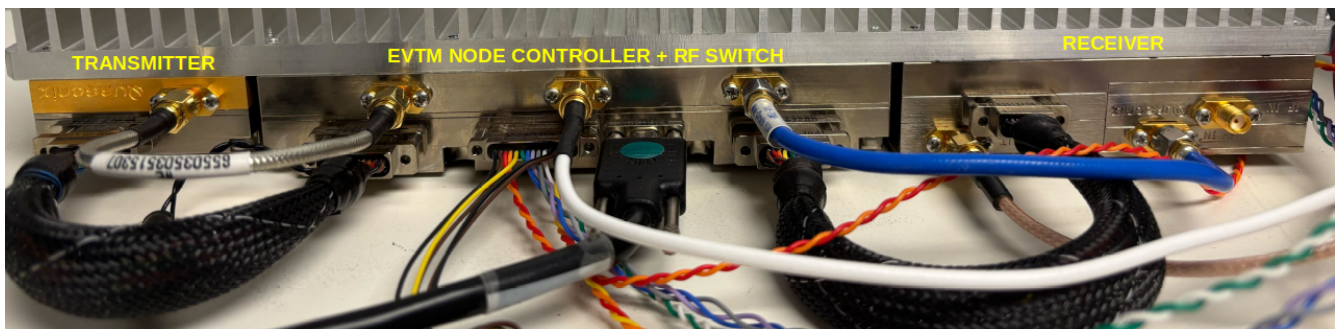


Figure 7 – Airborne System Component Interconnection

CHAPTER 4 - SYSTEM CONFIGURATION AND STATUS

The configuration of the Ground and Airborne systems differ in that the ground receiver and transmitter are configured with their own interfaces. The ground system relies on the existing graphical or API interfaces for control of the receiver and transmitter. The EVTM node-controller interface on the ground system differs from the airborne system when receiver and transmitter is operated independently. The airborne Radio Configuration allows the selection of link parameters which are then sent to the receiver and transmitter over serial control interfaces. On the ground system only the transmit parameters which affect the TDD timing are required to be set.

The timing of the TDD switching and duration of the uplink / downlink transmit times are set in the Timing Configuration window. The timing settings are required to be the same for the ground and airborne EVTM node-controllers. These settings determine the capacity allocated to the uplink and downlink as well as the packet latency.

EVTM Radio Configuration

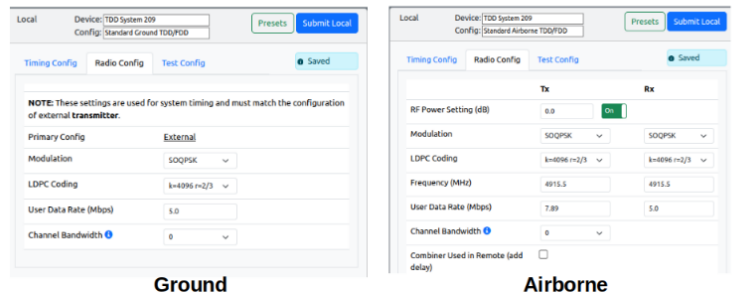


Figure 8 – Ground and Air Radio Configuration

EVTM TDD Timing Configuration

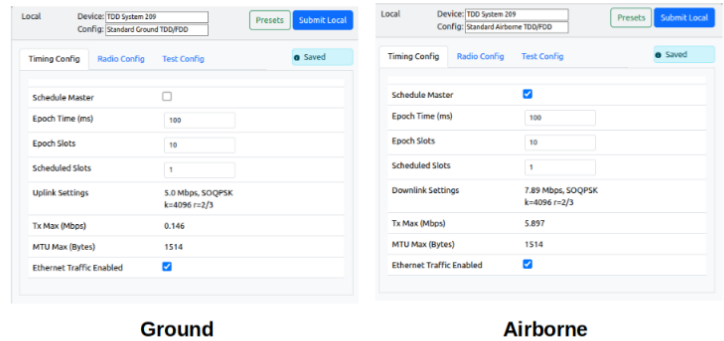


Figure 9 – Ground and Air TDD Timing Configuration

Num	Type	Ethernet Dest	Ethernet Src	Proto	IP Dest	IP Src	IPType	DPort	SPort
0	Pass	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	224.168.0.10	0.0.0.0	0x00	000000	000000
1	Pass	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	224.168.0.11	0.0.0.0	0x00	000000	000000
2	Pass	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	224.168.0.14	0.0.0.0	0x00	000000	000000
3	Pass	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	224.168.0.16	0.0.0.0	0x00	000000	000000
4	Pass	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	192.168.88.241	0.0.0.0	0x00	000000	000000
5	Drop	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	0.0.0.0	0.0.0.0	0x00	000000	000000
6	Off	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	0.0.0.0	0.0.0.0	0x00	000000	000000
7	Off	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	0.0.0.0	0.0.0.0	0x00	000000	000000
8	Off	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	0.0.0.0	0.0.0.0	0x00	000000	000000
9	Off	00:00:00:00:00:00	00:00:00:00:00:00	0x0000	0.0.0.0	0.0.0.0	0x00	000000	000000

Figure 10 – Transmit Packet Filtering Configuration

In order to provide tight control on the packets which are transmitted over the bandwidth limited TDD RF channel, a packet filtering capability was added to the EVTM node-controller. The transmit packet filter is applied to packets received on the wired interface to the EVTM node-controller. In the example shown the packet filter is set up to pass four multicast streams by their destination and traffic to a single host address while all other wired received packets are dropped.

Both the rack mount ground and compact airborne EVTM node-controllers also provide a hardware serial port access. This interface provides all of the control and status capability of the graphical interface and provides access to the unit when the graphical interface is not accessible.

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Commands:
Timing Config:
SM - Schedule Master Mode On/Off
ET - TDD Epoch Time nS
SE - Slots Per Epoch
SS - Slots For Non-Schedule Master
WE - Wireless Ethernet Traffic Enable/Disable

Radio Config:
RF - RF Transmit Power On/Off
VP - Variable Power Transmitter
MO - Modulation
LD - LDPC
FR - Frequency
DR - Transmitter Data Rate
BR - Receiver Bit Rate
BW - Channel Bandwidth Mode
CR - Combiner Enabled for Remote Receiver

Test Config:
PG - Packet Generator
DP - Drop Packet(s) From Transmit Queue
PI - RF Ping Test
LT - Link Test

Statistics:
PS - Packet Stats
PT - Packet Type Stats
QS - Queue Stats
RS - Receiver SYS Output In Terminal Control On/Off

Configuration:
BI - Set Browser Interface Mode
FP - Filter Wired Packets to Be Transmitted
IP - Set EVTM IP Address and Gateway
UP - User Presets
ST - Get Current Settings

Status:
LS - Link Settings (Capacity/Latency)
NS - Wired Network Status Information
SV - Show System Software Version Information
TE - Show System Temp Information
ND - Show Internal Watch Dog Statistics
NL - Show Internal Watch Dog Statistics (Link)

Other:
RB - Reboot Node Controller
TB - Transmit buffer control
    
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Figure 11 – Command Line Interface Configuration / Status

The EVTm node-controller provides access to user control and statistics by way of an API available at the IP address assigned to the unit. This provides for an external programmatic or script based automation of the configuration of the device. System configuration and run time statistics gathering can be performed via any scripting method that allows web based URL gets and puts running on Windows, MAC or Linux OS platforms.



Figure 12 – API Configuration and Status Interface

The link statistics that are displayed for the user are segmented by uplink and downlink. While the graphical interface and complete information is available at both ground and airborne local wired connections, during a test mission only the ground side would normally be observed. The statistics from the remote end are sent over-the-air at a programmable rate so that the remote end can be observed. A statistics logging capability has been added to store all statistics as csv files under user control.

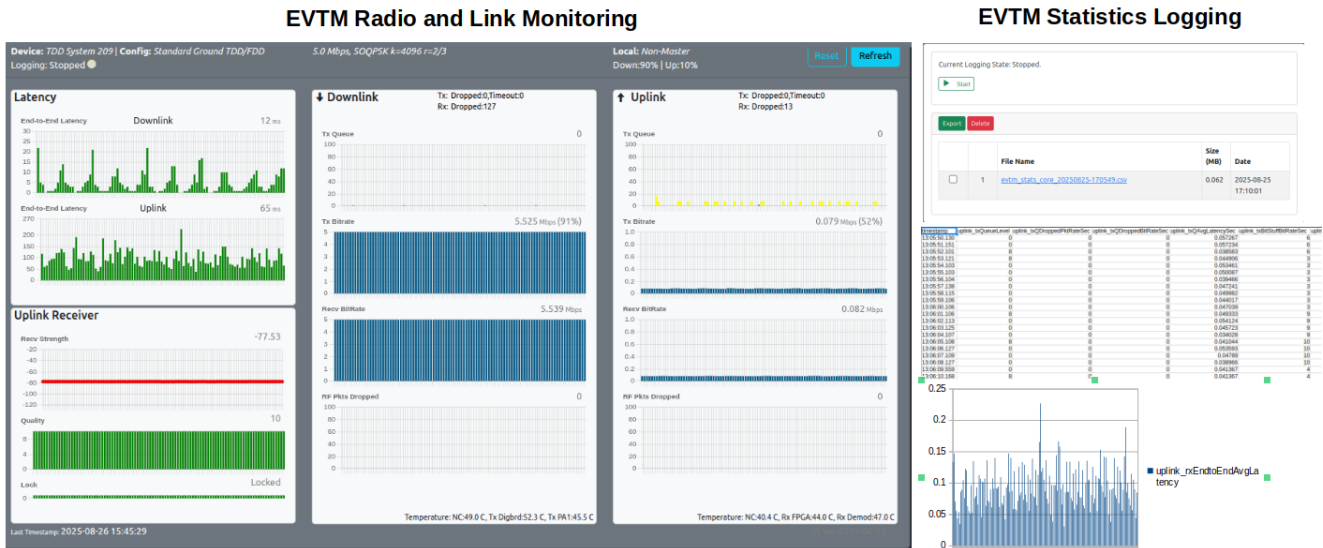


Figure 13 – Uplink and Downlink Monitoring and Statistics Logging

CHAPTER 5 - TESTING RESULTS AND SUMMARY

The TDD system is designed to work with all standard Aeronautical Mobile Telemetry (AMT) modulations, coding schemes, and user data rates. Before identifying a test channel to evaluate, validation of maximum IP throughput was conducted. Table 2 below details the maximum available user data rates for each of the AMT modulations. For LDPC, the maximum available rate is scaled relative to the codeblock length used [5]. Scaling factor for code rate=1/2 is 33/16, code rate=2/3 is scaled by 25/16, & code rate=4/5 is scaled by 21/16.

Ex. max user data rate in SOQPSK is 46 Mbps. $46 / (33/16) = 22.3\text{Mbps}$ max for SOQPSK-LDPC $R= \frac{1}{2}$

Modulation	No FEC	With FEC					
		Rate = 1/2		Rate = 2/3		Rate = 4/5	
		1024	4096	1024	4096	1024	4096
PCMFM	23	-	-	-	-	-	-
SOQPSK	46	22.30	22.30	29.44	29.44	35.04	35.04
STC	22.11	10.72	10.72	14.15	14.15	16.84	16.84
MHCPM	46	-	-	-	-	-	-

Table 2 - Maximum IRIG Defined Available User Data Rate (Mbps)

With the max available user data rate set, a standard TDD switching schedule was implemented to evaluate typical downlink IP throughput performance for each modulation. Table 3 below shows the measured downlink results in a TDD link with 100ms epoch time and a 10% uplink slot allocation.

Modulation	No FEC	With FEC					
		Rate = 1/2		Rate = 2/3		Rate = 4/5	
		1024	4096	1024	4096	1024	4096
PCMFM	18.2	-	-	-	-	-	-
SOQPSK	36.7	15.24	15.12	18.44	18.32	20.91	20.71
STC	17.2	7.95	7.89	10.37	10.26	12.22	12.12
MHCPM	35.1	-	-	-	-	-	-

Table 3 - Measured Downlink throughput (Mbps) 100ms Epoch Time, 10% Uplink Slot Allocation

There are many factors to consider when selecting which modulation type to use in a given telemetry link. Sensitivity threshold, synchronization time, and available data throughput are major contributions in identifying what best suits your implementation. For the scope of this test, the STC modulation is used with and without Forward Error Correction (FEC). In efforts to identify the trade offs of data throughput for each of the different FEC codes, a test channel of 10MHz Occupied Bandwidth [8] is set for each code.

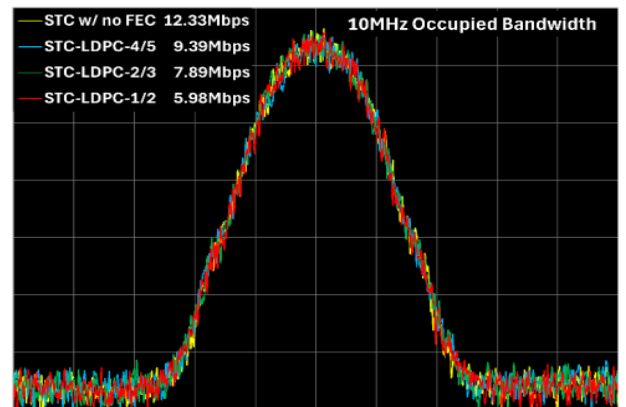


Figure 14 – TDD Uplink and Downlink 10 MHz Occupied Bandwidth

First the downlink only test case is measured to identify the bench line performance. Table 4 shows the measured IP throughput and max latency for a downlink only test case.

Modulation	No Uplink		
Downlink	Data Rate (Mbps)	IP Throughput (Mbps)	Max Latency (ms)
No FEC: STC	12.33	11.0	<=1
LDPC-4/5: STC	9.39	8.28	<=1
LDPC-2/3: STC	7.89	6.80	<=1
LDPC-1/2: STC	5.98	5.30	<=1

Table 4 - No Uplink Performance Data

Next, we introduce a minimum capacity uplink. As expected, there is a small loss in downlink throughput with the benefit of a low bandwidth uplink. Latency is increased due to the buffering during receive event windows. Table 5 shows the measured IP throughput and max latency for the 1% uplink test case.

Modulation	1% Uplink		
Downlink / Uplink	Data Rate (Mbps)	IP Throughput (Mbps)	Max Latency (ms)
No FEC: STC / SOQPSK	12.33 / 12.81	10.9 / 0.070	12 / 915
LDPC-4/5: STC / SOQPSK	9.39 / 9.76	8.20 / 0.050	21 / 948
LDPC-2/3: STC / SOQPSK	7.89 / 8.20	6.77 / 0.044	32 / 976
LDPC-1/2: STC / SOQPSK	5.98 / 6.21	5.10 / 0.030	40 / 982

Table 5 - 1% Uplink Transmit Time Performance Data, 1000ms epoch

Next, we introduce a higher capacity uplink. As expected, there is more loss in downlink throughput with the benefit of additional bandwidth in the uplink. Max latency is similar to the previous case due to having the same receive event window. The uplink receive event windows have decreased with the shorter epoch time, resulting in lower latency values in the uplink. Table 6 shows the measured IP throughput and max latency for the 10% uplink test case.

Modulation	10% Uplink		
Downlink / Uplink	Data Rate (Mbps)	IP Throughput (Mbps)	Max Latency (ms)
No FEC: STC / SOQPSK	12.33 / 12.81	9.42 / 0.750	12 / 92
LDPC-4/5: STC / SOQPSK	9.39 / 9.76	6.71 / 0.550	23 / 130
LDPC-2/3: STC / SOQPSK	7.89 / 8.2	5.65 / 0.430	33 / 142
LDPC-1/2: STC / SOQPSK	5.98 / 6.21	4.21 / 0.303	36 / 154

Table 6 - %10 Uplink Transmit Time Performance Data, 100ms epoch

CONCLUSIONS

Transforming a product line of packet based streaming telemetry system components into a switch-based time division duplex (TDD) capable system required a number of new telemetry techniques to be developed, verified and then integrated into a product line. The TDD capable modes were integrated in such a way that the same system performance as streaming telemetry was achieved after adjusting for capacity loss during receive-transmit, transmit-receive switching transition periods. With the TDD capable transmitter and receiver firmware updates available along with the EVTm node-controller hardware this new capability is being deployed as an channel efficient and less complex RF solution to providing a test article uplink channel while still maintain a highly efficient telemetry downlink.

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