ADVANCES IN PACKET BASED BI-DIRECTIONAL TELEMETRY SOLUTIONS

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ABSTRACT

Packet based bi-directional telemetry systems are being deployed on test ranges as well as commercial aeronautical/space systems. Multiple approaches have been developed each with their own set of capabilities and trade-offs. In this paper, bi-directional packet-based communications links used to transport data between test articles and ground systems are presented. Some of the current bi-directional telemetry systems are identified and compared. The comparison include the capabilities that they provide and the link methods that they employ.

INTRODUCTION

Packet based and Bidirectional telemetry communications systems are available for immediate use with additional systems also coming available. These systems often employ different mechanisms to achieve similar goals of bi-directional packet telemetry and the trade-offs are not always apparent to the end user. The first part of this paper will show outline the differences between the traditional bit streaming telemetry systems and ones that are based on a packet interface providing unidirectional and bidirectional links. The next section covers how the telemetry channel can be accessed and what might be gained or lost by selection of one method over another. This is followed by some examples of current and future systems and how they relate to the communication mechanisms described in the earlier sections.

CHAPTER 1 - TELEMETRY AND PACKET NETWORK EVOLUTION

Traditional Streaming Telemetry

Traditional telemetry has traditionally been composed of bit streams of critical information from an active source across a wireless interface which is sometimes a subset of all data sources being recorded locally during some activity of interest. These telemetry data streams are sent over an RF link due to the disconnected and inherently mobile nature of the item of interest. Initially packet streams of monitored data items were sent in whatever custom format was developed by the telemetry system designers. Unidirectional simplex links from the source of interest to a receiving and processing network has been the norm to minimize the additional complexity of supporting a communications uplink. As testing systems became more widespread efforts to coordinate and then standardize key aspects of the unidirectional telemetry streams occurred for the purpose of implementation efficiency gains and reliability. Streaming telemetry systems have evolved to employ technical improvements to address the signal environment challenges observed on test ranges.

Packet Based Networks

Within the telemetry solution space, a system is characterized by a single or small set of sources sending aggregated data in a continuous mode to a receiving network infrastructure. This contrasts with the evolution of mobile wireless networks where many users demand access to an available communications infrastructure and as both senders and receivers of data. After decades of development in the digital networks outside of the telemetry data application space there are methods employed which can provide additional capability when added to the current telemetry systems. Two of these methods considered here include the use of packet-based communications and bi-directional links.

Continuous Streaming

Data sources in a telemetry system are typically multiplexed into a single unidirectional digital stream of 1's and 0's transmitted contained within energy generated somewhere in the telemetry band of the RF spectrum as represented in Figure 1. The receiving network devices focus on the area of the RF spectrum being used and then employs mechanisms to recover the digital stream. The digital stream of 1's and 0's when recovered is then demultiplexed into the subsets of data as required by the devices representing the data sinks. A receiving end data recorder storing a complete mission might have a low requirement for further demultiplexing of the data whereas a receiving end instrument displaying one data source may require the system to demultiplex down to a part of the larger multiplexed flow of data.

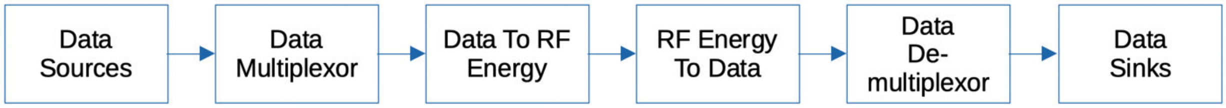

Figure 1 – Continuous Telemetry Transmission

Packet Streaming

Packet based systems impose a delineation of all data to be transmitted into a set of packets constrained between a minimum and maximum size with some examples shown in Figure 2. The minimum size is sometimes directly functional as in carrier sensing systems that need individual transmissions to have a certain minimum receive sensing duration in order to minimize a second transmission collision. Other times it is just a convention that is maintained. The maximum size of a packet is often of more interest to the system designer since the maximum packet size can affect the transport efficiency of data blocks from sources which exceed the maximum packet size. Within each packet there is a certain amount of control and destination overhead in the form of appended headers.

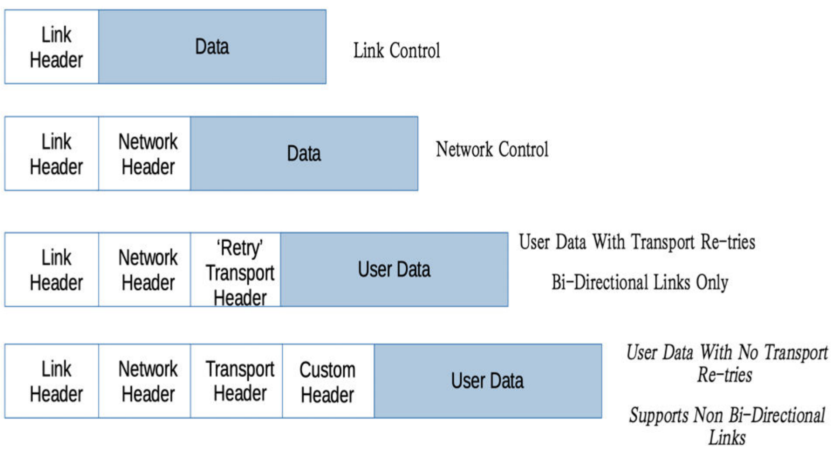

Figure 2 – Packet Structure Examples

Packets can be inserted into an existing streaming format such as is defined in [1]. The standard defines a method to incorporate Chapter 10 packets, integrated Network Enhanced Telemetry (iNET) Telemetry Network System (TmNS) packets, and Ethernet data packets into the pulse code modulation (PCM) stream. Packet formats have also been defined to natively support the sending of telemetry recorder data over an IP packet network. For instance, IRIG Chapter 10 [2] data from a data recorder can be sent as a UPD packet as specified in the standard.

Equipment employing conversion between telemetry and IP formats (TMoIP) [3] allows using a packet-based network infrastructure to move telemetry data between sites preserving the existing telemetry stream formats as data encapsulated in IP packets. The TMoIP hardware and software has resulted in leveraging IP based COTS solution for ground networks. These ground networks can then also be used to support end-to-end IP based telemetry.

Systems that employ streaming telemetry with embedded packets or using packet-based transport of embedded streaming telemetry provide an approach that leverages existing hardware/software systems. The solutions considered in the remainder of this paper employ packet-based capable RF transport mechanisms allowing the path from information source to sink to be completely packet based.

CHAPTER 2 – TELEMETRY CHANNEL ACCESS METHODS

A telemetry link channel access method could be configured in multiple ways between a mobile node of interest and ground assets as shown in Figure 3. Traditional streaming telemetry consist of one-way links which make exclusive use of the allocated frequency. Systems that provide bi-directional links either employ a frequency allocated in each direction as in Frequency Division Duplex (FDD) or shared channel access as in Time Division Duplex (TDD) access.

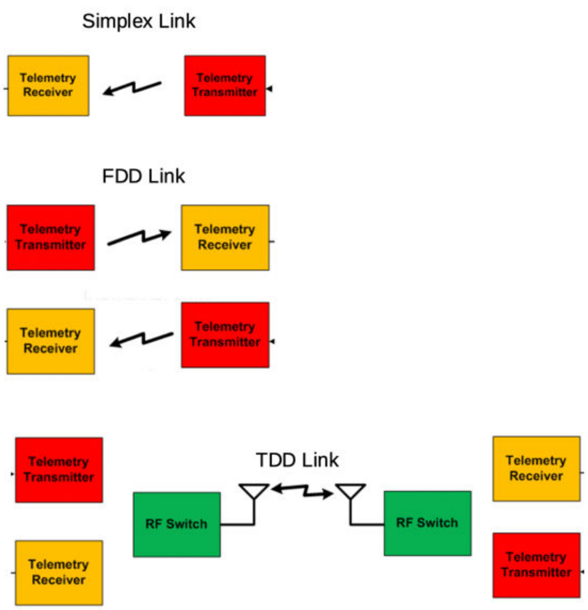

Figure 3 - Telemetry Channel Access Methods

Serial Data Simplex Link

A traditional telemetry link is composed of a transmitter sending aggregate data and receiver locked on and recovering the data is described as employing a simplex link. Only one transmitter is present in this case with the number of receivers determined by mission needs. Only one RF spectrum allocation is needed to support the simplex link, which is designated as a center frequency and bandwidth. The frequency is specified as a center frequency value and the bandwidth is determined by the data rate and modulation scheme employed. Multiple simplex links can be aggregated together when the telemetry data rate requirements exceed the capacity of a single Simplex link.

IP Packet-based Simplex Link

When combining simplex links with existing packet-based network systems the lack of a return path requires certain considerations. One consideration is when sending network packets sent to a specific host address. For an Ethernet bridge type transmitter, a static IP address to MAC address association of the host IP and destination must be inserted since two-way address resolution protocols do not work over simplex links. If the transmitter provides a router capability, then then a next hop network route is put in place to direct the packets to the IP interface of the router-based transmitter. Multicast packets can provide a good mechanism to send packets on a packet based simplex link without need for host MAC to network resolution. Multicast packets are sent like broadcast packets in that they both directly link the network address to a MAC address. Multicast packets also have a range of values which can be used for different data flows.

Bi-Directional FDD Link

A Frequency Division Duplex (FDD) telemetry bi-directional link is composed of two frequencies one allocated for the telemetry downlink and a second allocated to the uplink. The uplink transmitter center frequency is separated from the transmit center frequency by an amount, determined in part by the capability of the RF front end components to isolate the much lower level receive signal from high power transmit signal interference. One example of a FDD system used in a telemetry links is the EVTM ethernet encoder/decoder bi-directional telemetry system. This system is currently in use in telemetry applications typically with larger downstream data flows often composed of video streams and a lower capacity uplink control link.

Bi-Directional TDD Link

A Time Division Duplex (TDD) system uses a single frequency with sequenced transmit event with two or more transmitters. The method of providing transmit access to the single frequency being shared could be based on synchronized timing present at all transmitters using GPS / or wired based timing protocols to a common time source. An alternative approach is to have a single transmitter provide timing for the other transmitters in the network. The transmitter providing timing in this approach would typically be the test article in a telemetry system with ground antennas receiving uplink transmission schedule timing from the test article.

Channel Access Comparison

Table 1 shows some of the key aspects of channel access methods for telemetry links.

Table 1 - Channel Access Comparison

Link Type	Channels	IP Network Compatible	Link Data Rate Asymmetry Support	Operating Frequency Agility	R-T Switching Overhead
Simplex	1	With stream packet insertion and removal	N/A	High prior to test, requires change method during test.	None
Simplex Packet	1	Yes, with some restrictions due to one-way operation	N/A	High prior to test, requires change method during test.	None
FDD	2	Yes	Depends on frequency allocation minimum	Related to RF implementation of Rx-Tx isolation	None
TDD	1	Yes	Yes	Yes	Yes

TmNS TDD Based Telemetry

The TmNS standards [5] specify a telemetry solution consisting of a bi-directional TDD system with synchronized time-based coordination between the transmitters in a network. The TmNS telemetry systems include a GPS interface or wired interface support for IEEE 1588 to implement time synchronization at each node. Time synchronization is required to coordinate transmit start/stop of transceivers sharing a single RF frequency. From a network device standpoint, the TmNS transceiver is defined as a layer 3 network routing device which relies on IP routes either static or dynamically assigned to achieve end-to-end packet forwarding between host computers or network devices connected at either end of a telemetry link.

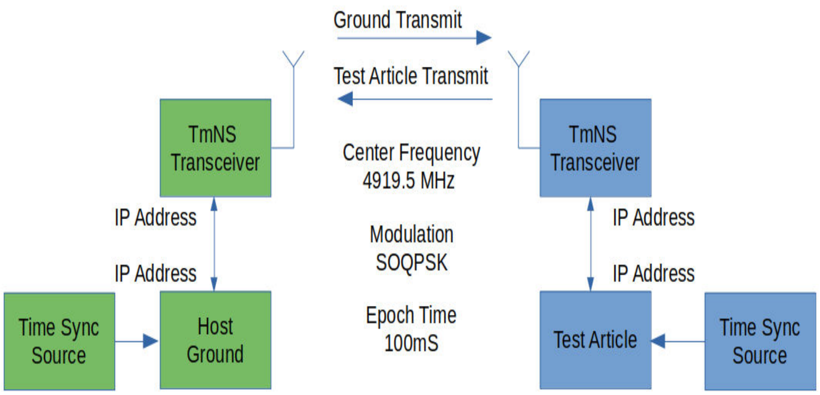

Figure 4 – TmNS Transceiver Test Setup

A network of two TmNS transceivers is as shown in Figure 4. A GPS or wired IEEE-1588 time master is connected to each TmNS transceiver as a time source. A transmit schedule is loaded from an XML configuration file. In the XML file the time associated with each transceiver transmit time is defined as transmit opportunities. Each transmit opportunity has a defined start and stop time as shown in the example TmNS transmit schedule in Figure 5. The start and stop times are defined as relative to the Epoch time specified in the XML configuration file.

GUARD	GND: START	GND: STOP	GUARD	TA: START	TA: STOP	GUARD	GND: START	GND: STOP		GUARD	TA: START	TA: STOP	
2000	2000	11500	1000	12500	24000	1000	25000	36500	ooo	1000	87500	99000	Time in uS

Figure 5 – TmNS Transmit Schedule

The configuration of the transmit opportunities and guard time are shown for a 100 mS repeating epoch that was configured by the same XML file which was contained on each of the two transceivers. The transmit configuration is defined for 50% duty cycle between the two directions. Other transmit duty cycles are such as an asymmetric higher capacity down link can be defined by a smaller transmit times and/or less transmit opportunities allocated to the ground transmitter. Within a transmit time a TmNS transceiver sends one or more bursts of an SOQPSK waveform containing a synchronization pattern at the beginning of the transmission. The time and frequency synchronization required to recover the data correctly is derived from this initial synchronization pattern. This method of burst-based communications as applied to range telemetry is specified in the TmNS standard. This method differs from approaches that switch existing streaming telemetry modulation on and off during sequenced transmission periods.

Two Channel Continuous Frequency Division Duplex (FDD)

The EVTM-FDD [6] transceiver shown in Figure 6 is an example of a bi-directional FDD packet-based telemetry link providing independent uplink and downlink frequency operation. It uses a COTS transmitter and receiver modules coupled with an ethernet encoder/decoder module and separate antennas and/or frequency diplexers to isolate the transmit signal from the receiver input.

Figure 6 – EVTM FDD Transceiver

The encoder / decoder module is a standalone device which contains an Ethernet interface that provides a conversion between Ethernet packets and transmitter/receiver serial data interfaces. Ethernet packets that are received by the encoder are validated and then wrapped with HDLC packet framing to preserve the packet boundaries when sent over a serial telemetry link. A 32-bit CRC is sent with the Ethernet packet over the telemetry link and is validated by the decoder device before transmitting the packet on the wired ethernet on the receiving end.

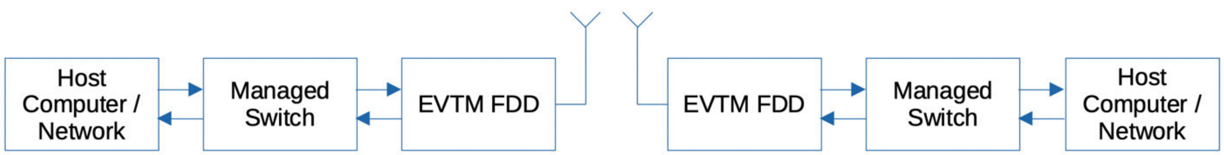

Figure 7 – EVTM-FDD Configuration

One of the distinct advantages of an FDD approach is the reliable low latency that can be achieved when the channel is not shared between uplink and downlink as with the TDD approach. In Figure 8 a summary of measured round trip message times is shown for two modulation types and data rates from 1 to 40 Mbps. In comparison a TDD system will always have a larger average latency value determined by the slot schedule and sharing of the channel.

PCMFM, Standard 56 Byte Packet Ping			
Rate (Mbps)	min(us)	avg (us)	max (us)
40	-	-	-
20	286	339	449
10	392	452	532
4	722	784	929
2	1278	1293	1346
1	2384	2443	2693

SOQPSK, Standard 56 Byte Packet Ping			
Rate (Mbps)	min(us)	avg (us)	max (us)
40	248	283	371
20	302	346	539
10	411	456	673
4	744	794	962
2	1292	1320	1555
1	2407	2485	2572

Figure 8 - TDD Round Trip Latency Times

The EVTM-FDD unit has a fixed 100 Mbps Full-Duplex (non-auto negotiate) wired interface and transmits all valid packets received within the 2000-byte MTU size. As a result of the rate mismatch between packets received on the wired interface and scheduling on the lower rate RF interface, packet buffers are implemented on the Ethernet receive to RF transmit interface to provide rate adaption. The EVTM-FDD is often used with a managed switch to allow for limiting the over-the-air bridged network traffic using switch-based bridging protocols and user configurable settings.

The configuration of an EVTM FDD system is basically the same as setting up a standard telemetry link though with transmitter and receiver settings in both directions. The operating parameters such as data rate, modulation and frequency are the same as the ones available in the standard transmitters and receivers. The data rate selected for an application is driven by parameters such as the required SNR, maximum desired range, transmit power and antenna gain. Typical use cases for fielded systems are to set the downlink for a high rate up to 46 Mbps or as dictated by the operational link budget. The uplink is typically set to a lower data-rate since for most applications this it almost often used for low-rate control information flow. The lower data rate in the uplink allows the use of a separate lower gain antenna with isolation from a standard high gain antenna used on the downlink simplifying the implementation. If the same antenna is used, frequency isolation circuitry using a frequency diplexer is required to provide receive signal isolation from the higher power transmit signal.

Single Channel Time Division Duplex (TDD)

The EVTM-TDD transceiver is an example of a switched packet-based time division duplex telemetry approach. The transceiver couples a node controller unit with standard streaming telemetry components. Like the EVTM-FDD transceiver it uses both COTS transmitter and receiver units. The node controller provides the interface to the wired network on each end of the telemetry link. Initially offered as an Ethernet bridge unit with the same functionality as the hardware based EVTM-FDD unit it has the capability to provide an IP routing function as well. As shown in Figure 9 the node controller consists of a top digital section with transmitter and receiver data / control interfaces. The bottom section is an RF interface which switches between transmit input and receiver output connections to the antenna interface under control of the node controller digital section.

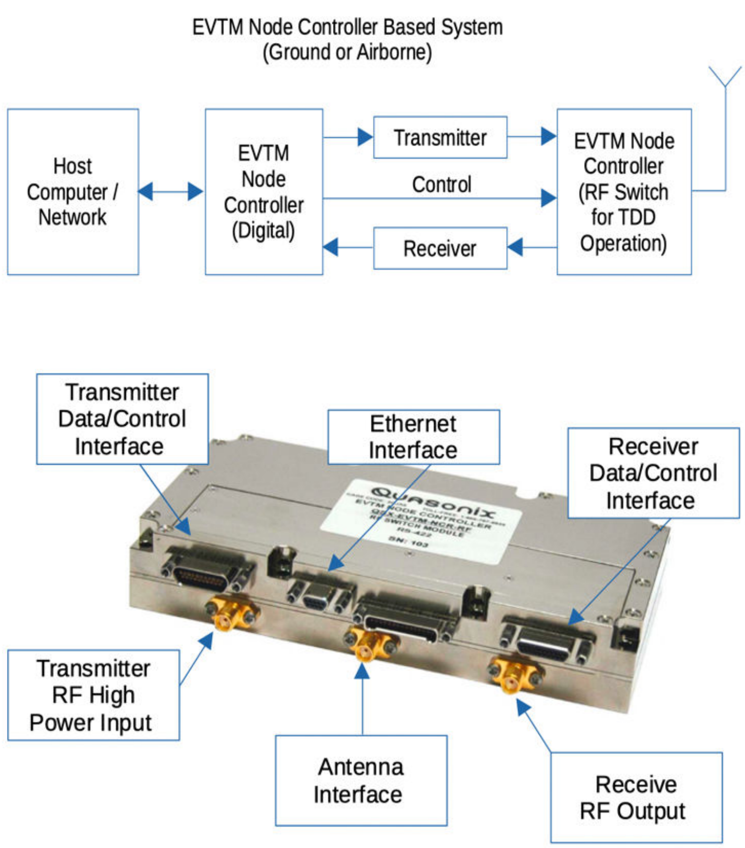

Figure 9 – EVTM TDD Node Controller Based Transceiver

The node controller can be used with the integrated RF switch when supporting a TDD switched telemetry link or with antenna matching components employed with a FDD system. The EVTM TDD provides a TDD channel access mode which designates a single node as the provider of transmit channel access timing which does not require the use of external time synchronization at each node. A schedule message is sent by the designated node each epoch which instructs the other nodes when the channel is to be access for transmissions. The schedule master node is most often the test article and with the ground transceivers accessing the channel based on the timing set by the schedule master.

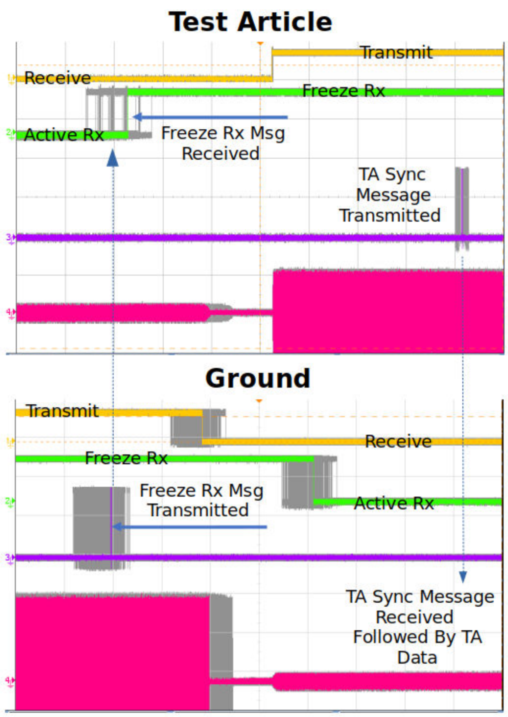

Figure 10 - Switched Telemetry Receiver Control Sequence

In addition to the schedule message to coordinate transmissions, receiver freeze, and sync messages are added to the transmit data as shown in Figure 10. At the end of each transmit period the transmitter sends a Receiver Freeze message over the RF link which is decoded by the node controller which then asserts the hardware freeze line to the receiver. The receiver uses this stored state to begin acquisition when an active receive period resumes. This freezing of the receiver state while the node is in active transmit has proved to decrease the required acquisition time during a new receive cycle. Following the return to active receive the first packet received is a synchronization packet. The synchronization packet is small packet which contains a correlation pattern used by the receiver to determine link quality during initial re-acquisition.

For support for switched telemetry using synchronization at each node and local transmit schedules as in the TmNS standard, the waveform timing would be much the same as shown for the master scheduler operation. The difference being the lack of a master schedule being transmitted and transmit times instead being stored locally at each transceiver. The receiver freeze and synchronization messages would be sent in each allocated transmission opportunity to allow the receiver to store settings and then quickly acquire the resumed switched telemetry signal.

CONCLUSIONS

As new packet base and bidirectional capability is introduced into telemetry systems in the coming years new communications systems will continued to be deployed and adapted to user's needs. Several approaches were shown for the implementing these systems. The TmNS based transceivers using a non-streaming SOQPSK modulated burst packet transmission in a TDD synchronized transmit window. The switched telemetry packet based bi-directional TDD transceiver systems leverage existing telemetry components with slight modifications to receivers to process receiver freeze and sync messages sent by the transmitter. The FDD approach requires two frequency allocations though uses telemetry components as is with no modifications and provides the lowest latency due to the independent uplink/downlink channels. As these packet based bi-directional systems continue to be deployed in the test environments more will be learned about what solutions work best in specific test environments.

REFERENCES

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