

# **PACKET-BASED TELEMETRY NETWORKS OVER LEGACY SYSTEMS**

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## **ABSTRACT**

The telemetry industry anticipates the tremendous potential value of adding full networking capability to telemetry systems. However, much of this potential can be realized while working with legacy equipment. By adding modules that interface transparently to existing equipment, continuous telemetry data can be encapsulated in discrete packets for over the air transmission. Packet fields can include header, sequence number and bytes for error detection and correction. The RF packet is transmitted without gaps through a standard serial interface and rate adjusted for the packet overhead – effectively making packetization transparent to a legacy system. The receiver unit performs packet synchronization, error correction, extraction of stream quality metrics and re-encapsulation of the payload data into an internet protocol (IP) packet. These standard packets can then be sent over the existing network transport system to the range control center. At the range control center, the extracted stream quality metrics are used to select the best telemetry source in real-time. This paper provides a general discussion of the path to a fully realized, packet-based telemetry network and a brief but comprehensive overview of the Hypernet system architecture as a case study.

## **KEY WORDS**

Network, Ethernet, TCP, IP, UDP, ATM, Source Selection

## **INTRODUCTION**

The range telemetry infrastructure consists in its most basic form of test vehicle (TV) sources of data, ground receiving station, and a central control station to which the received telemetry data are relayed by the ground receiving stations. Currently, the data are transmitted in continuous streams without framing. Being continuous and real-time, it is very difficult to choose between multiple streams based on a quality of service metric. Synchronizing streams from the same source but from different receivers is likewise very difficult. Furthermore, the heterogeneous structure of the data transmit, relay and collection channel requires specialized skills that leave the range vulnerable to personnel turnover and the control and distribution of the data problematic.

In addition to the shortcomings of the existing system, there are many features that are difficult or impossible to add without a packet-based network. Nearly all these problems and

improvements have ready solutions for a packetized network using standards-based, proven network protocols. For example, Packetization of the telemetry data permits time alignment and source selection algorithms that can operate efficiently, accurately and at real-time. Issues such as flexibility in the distribution and access of data, security and authentication with respect to data access, scalability, sharing of limited bandwidth, quality of service and other problems have been widely studied and solutions commercially available for such networks.

An example of a nearly ideal solution in terms of the improvements discussed above and in terms of simplifying the network topology would be a TCP/IP network over Gigabit Ethernet. The use of standard packet network technology provides a large pool of personnel with the required knowledge for system operation and a correspondingly large pool of sources for the off-the-shelf hardware with lower cost and scalability.

## **OVERVIEW**

The ideal solution cannot, of course, survive in a vacuum. Existing equipment and infrastructure must be incorporated into the upgrade path. This provides acceptance of a new approach, lower risk and lower transition cost. The existing continuous, real-time data stream can be broken up into discrete data units and encapsulated into a standard packet structure with minimal impact on the legacy system. An example of such a system, currently in development by Nova Engineering and scheduled for demonstration in 2005, is used as a case study to illustrate some of the concepts discussed and validate their ability to be realized in existing hardware. Figure 1 provides an overview of the Hypernet system. The key components are the Baseband Data Processor (BDP) which provides continuous data to packet translation, and the Network Data Processor (NDP) which transforms the over-the-air packet to a standard packet protocol (IP over Ethernet).

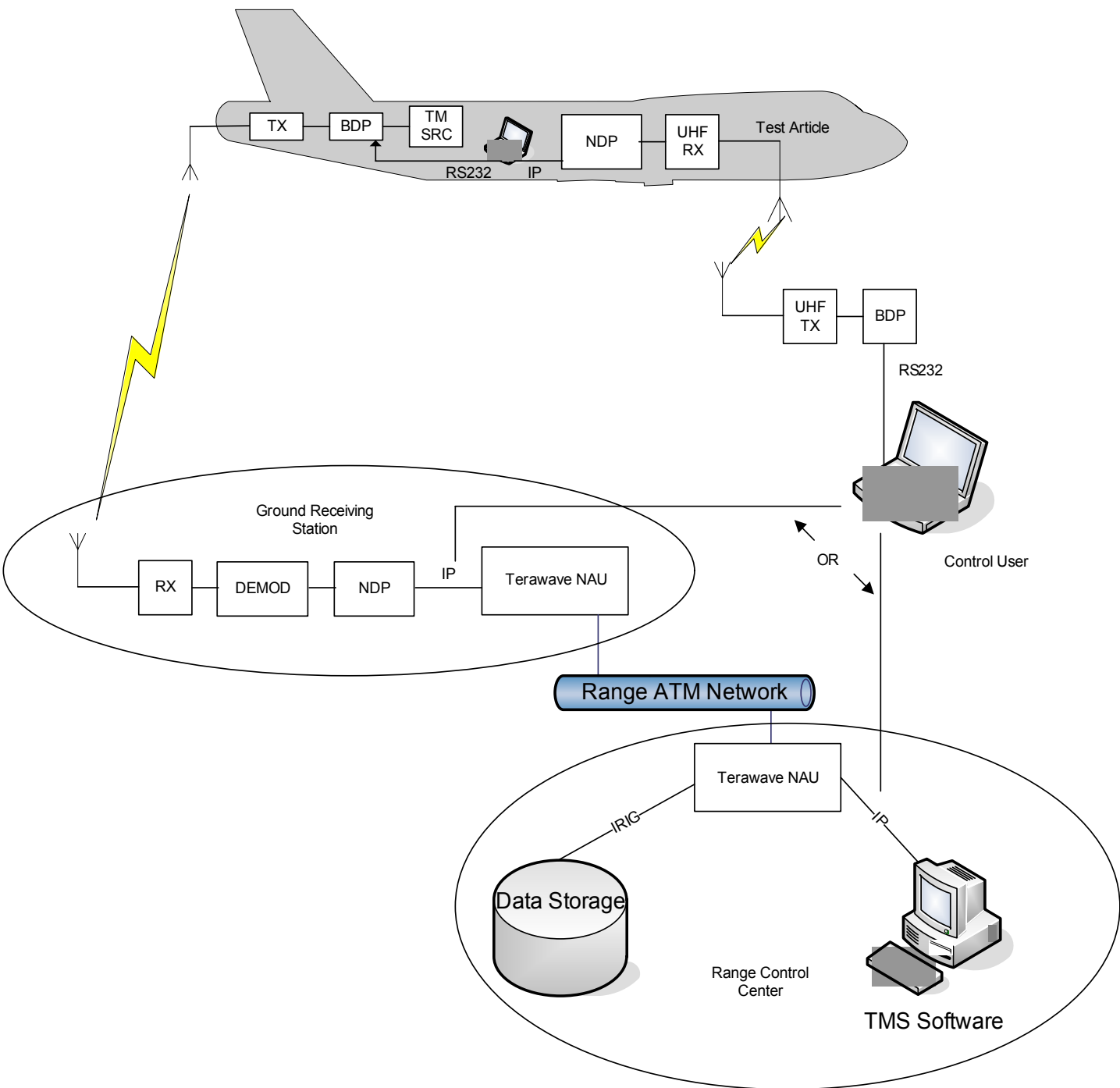


Figure 1 - Hypernet Case Study of Networked Telemetry over Legacy Infrastructure

This general discussion and Hypernet case study clearly demonstrates the validity of growing legacy systems into the next generation, fully networked, airborne telemetry infrastructure.

A survey of the “state of affairs” over deployed networks in both the military and commercial sectors immediately marks TCP/IP as the dominant network protocol suite. This is the obvious first area of investigation for network planning.

## PACKET ENCAPSULATION OF CONTINUOUS STREAM

Accepting the value of TCP/IP based networking, the challenge becomes the translation of a continuous telemetry stream into discrete data packets. The challenge becomes greater, but the payoff even more so, if the translation can be performed in a manner transparent to the existing telemetry transmitter and receiver. This is expressed in the following diagram.

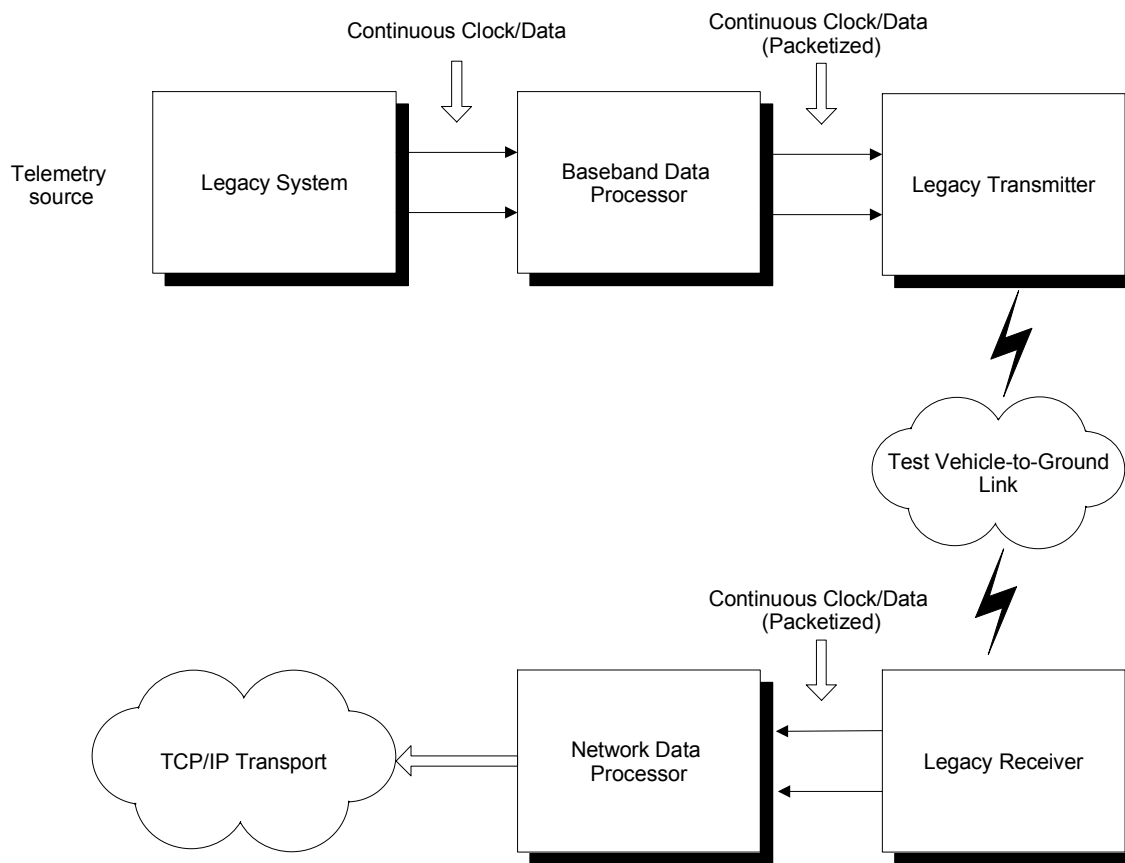


Figure 2 – Packet Processing over Legacy Hardware

The power of this arrangement lies in its flexible application to a wide range of existing systems. The term “Baseband Data Processor” refers to the unit that takes the legacy waveform and produces a continuous, though packetized, output data stream whose data rate is adjusted for the packet overhead. The packet structure of the BDP will be optimized for over the air transmission and need not conform to any standard. The “Network Data Processor”, on the other hand, will encapsulate the desired elements of the over the air packet into a standard structure such as UDP packets (a member of the TCP/IP suite) over Ethernet.

The ability to be realized in existing hardware with transparency to the legacy system is the result of ever growing advances in programmable logic devices. The ability to estimate and track incoming baseband data and output a continuous though packetized stream over a wide range of data rates, requires high-performing devices and robust algorithms.

As an example, in Nova's Hypernet network telemetry system, a control system based on a nominal fill level in an input FIFO provides the required data rate detection and tracking. Modern FPGAs provide deep FIFOs with flexible interfaces. By setting the nominal fill level, a tradeoff is established between robustness, adaptation rate and system latency. The user can set an initial data rate through the terminal interface or the system can be left to acquire without an initial set point. Again, flexibility is built into the system to provide optimization to a given test environment.

This flexible rate adaptation serves an additional purpose. The Hypernet system supports the insertion of low rate, control data packets from the test vehicle. This is shown for the uplink in Figure 1 and on the downlink in Figure 5. The output rate of the baseband data processor is adjusted sufficiently to account for packet overhead and these control packets. In the current system, 2 kbps are allocated to control data. The source for control data is a host system connected to a standard RS232 port on the BDP. This is the same port that provides the configuration and control interface to the BDP unit itself. On the receive side, control packets are given a different destination address and unique identifiers to allow flexibility in their handling. Note that control packets can originate from the TV or from the ground station providing the uplink.

Between the ends of this translation block lies nearly limitless potential for system improvement. Once the data has been packetized, a vast array of error correction coding, encryption, and informational tagging can be applied to the payload, just to name a few examples. This information aids in data recovery and security. The additional informational tags provide sufficient flexibility in processing the data to meet the particular needs of any application.

In the case of Hypernet, these additional fields are used for identifying the source of the stream (Stream ID), the sequence number of the packet and packet type. For error detection, a cyclic redundancy check (CRC) is calculated for the header alone, due to it's critical role in interpreting the entire packet, and a separate CRC for the header along with the payload data. For error correction, a (255, 239) Reed-Solomon code is used. A framing word is added to the beginning of the packet to permit frame synchronization in the NDP. Figure 3 shows the over-the-air packet structure used in Nova's Hypernet system.

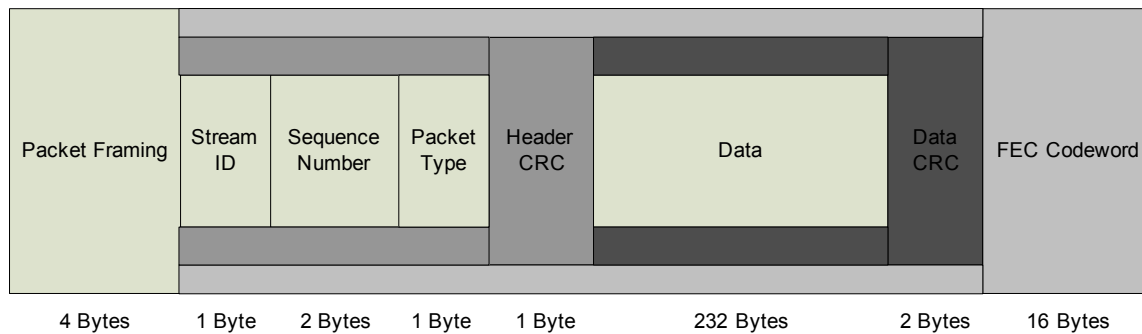


Figure 3 - Hypernet Case Study: Over the Air Packet Structure

It is this packet that is received by the NDP and disassembled in order to perform error correction, determine stream quality information and to encapsulate the telemetry packet into a UDP, Ethernet packet for network transport. The flow from Telemetry source to packet Transport is shown in Figure 4 below.

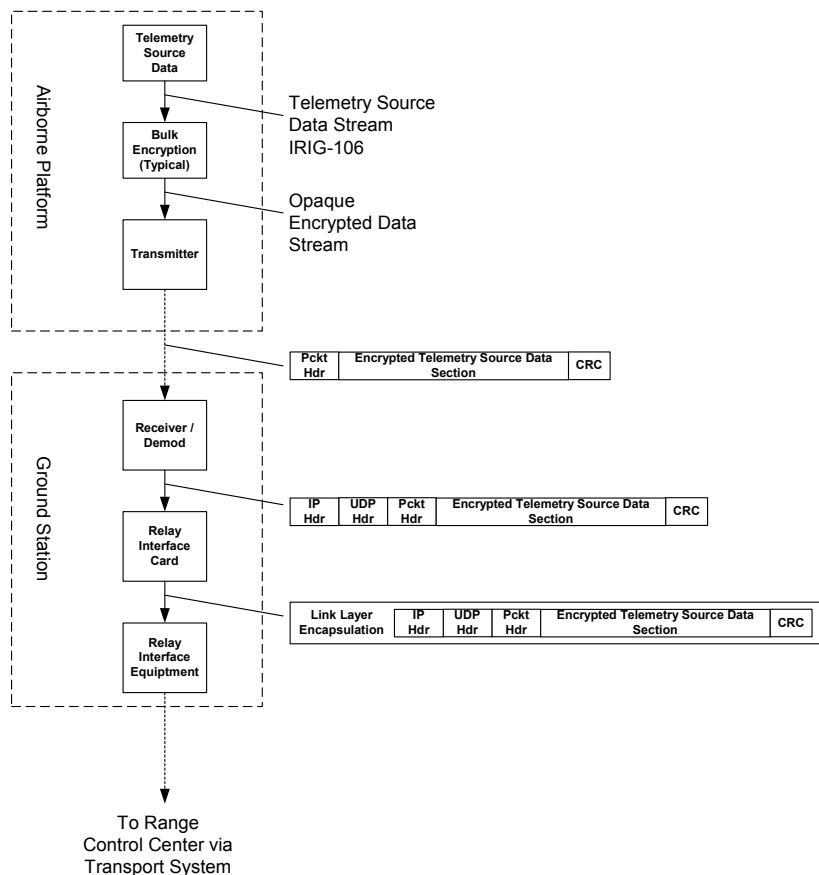


Figure 4 – Flow of data from telemetry source to packet transport

## ROUTING OVER ATM

The existing transport system to the Range Control Center is over an ATM backbone. Terawave units provide the routing of Ethernet packets over the ATM network and source selection (discussed later) on the receive side. Reconstruction of the data clock using packet sequence numbers and the rate of packet reception permits clock reconstruction when required by the application. Figure 5 depicts the routing of two separate TV streams, received by two different NDPs all of which need to be sent over the ATM in separate channels to allow for best source selection. In addition, control packets and stream quality packets must also be routed over the ATM network.

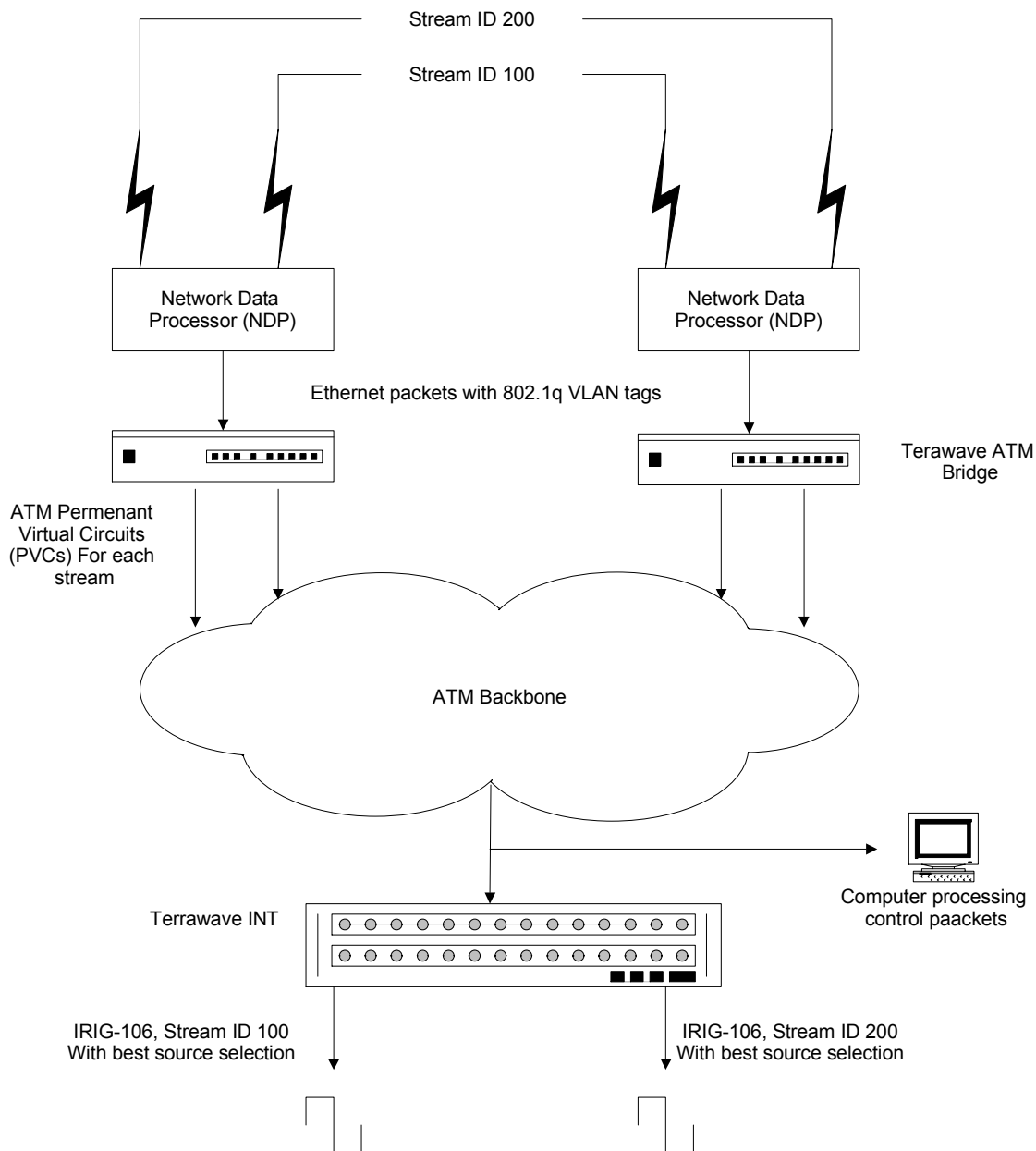


Figure 5 – Flow of data from telemetry source to packet transport

The ATM system requires a Permanent Virtual Circuit (PVC) to be established for each stream. By far the simplest method for designating different streams from each NDP is by using the 802.1q extension to Ethernet. This standard provides for a Virtual LAN (VLAN) ID tag to be inserted in the Ethernet packet's header. Because this is part of the Ethernet specification, existing network hardware is able to use these tags for fast switching of packets. The Hypernet system uses VLAN tags based on the stream ID of the telemetry source and the particular NDP that receives the stream. The ATM bridge uses the VLAN tag to establish the PVC that connects the ground receive station to the range control center.

The use of VLAN tags simplifies the interface with the Range ATM Network. In an all-Ethernet environment, VLAN tags would not be necessary and an even greater degree of network flexibility would be possible. Nevertheless, the use of 802.1q packet extensions remains in the domain of standards-based networking and further demonstrates the ability to operate within the confines of the existing range network infrastructure.

### **STREAM QUALITY**

The quality of the stream is based on the number of uncorrected Reed-Solomon symbols averaged over a programmable number of packets. This metric was chosen since it was readily available and directly corresponds to the quality of the stream. For example, a stream quality measurement on a single packet of 3 uncorrectable symbols might represent 3 to 24 bit errors since a single Reed-Solomon symbol consists of 8 bits. On the other hand, if bit errors were used as the stream quality metric, 20 bit errors spread over enough symbols might represent a more severely degraded stream given the form of error correction being employed. In other words, the stream quality metric must suit the application. In this case, it directly corresponds to the error correction employed and provides some indication of the whether the corrupting noise occurs in bursts or more uniformly throughout the packet.

Another possibility for embedding stream quality information in the packets would be to include an RF measure of signal strength, an estimate of the bit errors, or any number of useful statistics all of which could be added to the packet at the NDP. Having these data in each packet suggests the possibility of more advanced algorithms and the incorporation of several sources of stream quality information for automatic selection of the best telemetry stream from among several candidates.

### **BEST SOURCE SELECTION AND USER INTERFACE**

In the existing system, best source selection is based on an average stream quality using an average provided by the NDP and sent to the Range Control Center's Terawave INT. Currently, source selection is a manual process in which the operator has access, in the software graphical user interface (GUI), to the stream quality metric for each stream and a push-button method of selecting which stream is routed to the TSIM/TTL port of the Terawave unit.

Additional alerts can be brought to the operator's attention using a simple and clear display in the source selection GUI. Using simple network management protocol (SNMP) packets containing system alerts and alarms, messages such as receive synchronization loss or the absence of an input data clock at the NDP provide quick, on-screen indication of stream degradation and the possible need for intervention.

Intervention is possible by switching telemetry streams or by direct interaction with the test vehicle. The Hypernet system, as would any complete networked telemetry solution, also sends packetized data from the ground back to the TV. Control data was discussed previously with respect to the TV-to-ground link. However, control packets can also be sourced by the ground and transmitted to the TV. The Hypernet system employs off-the-shelf FM transmitters and receivers in conjunction with a BDP on the ground and a network processor on the TV to complete the loop on the TV / ground station link. The uplink provides capability for real-time mission control and bandwidth allocation as well as voice over IP (VoIP).

## **CONCLUSIONS**

With the telemetry data now in standard TCP/IP packets, the transition to a fully realized telemetry network is underway. The Hypernet system leverages the existing Ethernet and ATM infrastructure. Adhering to the layered network paradigm, however, will allow the same system to live on top of many different physical transport mediums. The physical layer can be optimized for the specific test environment.

Similarly, there is no limit to the potential connectivity of the telemetry network using commercially available hardware. As one example, the Novaroam line of mobile routers supports an adaptive, ad-hoc routing, wireless network. By simply inserting this component into the topology described here, the capability for adding mobile ground vehicles to the system is gained with minimal effort.

In short, the future of Hypernet is bound up in its flexibility. The challenge is to define the requirements, constraints and desired feature set of the application then leverage the programmability of the Hypernet system