Remote Diagnostics for Data Acquisition Systems

by

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Abstract

This paper overviews research being conducted at IRIS in the field of data acquisition for motorsport applications. The research is part of a collaboration between IRIS, the Cooperative Research Centre (CRC) for Intelligent Manufacturing Systems and Technologies (IMST) and an industrial sponsor, Motec Pty. Ltd. The research commenced on June 2001 and the expected completion date is June 2003. The purpose of the research is to evaluate and understand the availability and performance characteristics of current and emerging wireless technologies that can be deployed to provide network coverage (public or private) for mobile and static telemetry applications. This paper focuses on the use of data telemetry in motorsports events, for application in data acquisition systems (DASs) which are used by racing teams to acquire system information. This research investigates how both technologies and architecture can address these issues and will make recommendations based upon these findings. The analysis is based on the International Standards Organisation (ISO) Open Systems Interconnection (OSI) reference model.

1. Introduction

DAS technology is a relatively recent development within the motorsports industry and has been developed to enable racing teams to measure the performance of both their car and driver during a motorsport event. Its application commenced in 1983 when BMW used one of the first data telemetry systems in their car at Brahbam *[Valken 2000]*. The first remote diagnostic application emerged two years later. At the time this research commenced, the most advanced DAS system was the "Real-time and Burst" transmission model, where a bank of PCs collected and analysed approximately 50 channels of data via radio-frequency (RF) telemetry *[AtlasF1 1998, HP 1999 & Galpin 1995]* monitoring more than a hundred parameters.

As was often the case in data transmission systems, the employed architecture was not standardised and each team developed its own unique solution according to the requirements of their formulae, tracks and the sensor technology used in each car. This generally resulted in point-to-point networks that were developed to solve data retrieval problems, rather to provide a flexible infrastructure that could support real-time data telemetry.

2. DAS Systems

2.1 "Real-time and Burst" transmission model

In Formula 1 motorsports, data telemetry was generally realised in two forms, that is via:

- Real-time transmission
- Burst transmission.

Racing teams typically partnered up with mobile telephony cellular network service providers to receive their data in real-time. A commonly employed transmission technology was the global system for mobiles (GSM), which had throughput limitations. As such, only essential information could be continuously monitored via RF telemetry during a race. The rest of the information for each lap had to be stored in memory and then transmitted to the service pits via data burst using microwave technology *[Gray 2001]*. This technique enabled two to three megabytes of data to be transmitted within a couple of seconds *[AtlasF1 1998]*. The raw data was then often interpreted into graphical information, which the data acquisition engineer could then interpret and then discusses with the driver.

This system was proven to be successful, but had limitations:

- A public network was often used where access to RF resources decreased as more spectators attend.

- Established teams often had advantages over newer teams that did not have the capital for a full telemetry system.

- Video was not supported by this system the current system.

2.2 Next Generation DAS Networks

To overcome the above problems, it was considered that the next generation of DAS networks should have the following design parameters:

- Utilisation of a centralised distribution architecture.
- Event based design (multipoint to point), not car based (i.e., point-to-point)
- Support for data packet transmission as well as TCP/IP.
- Support for real-time streaming data.
- Provision of reliable and secure data transmission.
- Readily transported between locations.
- Capable of supporting video.

3. Key Network Issues

3.1 Overview

When designing the next generation DAS architecture it was important to consider the key issues that would impact on the design of the network. From investigating the various, available technologies and a number of actual motorsports race-tracks, a number of key design issues were identified. These are summarised in Sections 3.2 – 3.4.

3.2 Doppler Shift and Change

The doppler shift is a phenomenon where a frequency or a wavelength of a signal shifts from its assigned frequency. It occurs as a result of either the transmitter, receiver (or both) moving. A typical example of this would be a police siren (transmitter), where the pitch of the siren shifts positively as the car move towards a listener (receiver) and negatively when they move away. In radio systems the Doppler spread can cause Inter Carrier Interference (ICI), resulting in loss of connectivity. The general equation for Doppler spread is

$$f_D = f_{Tx} * (V/c) \cos \Phi$$

where a racing car travelling through a 100m radius microcell, at a speed (V) of 300 kph and transmitting at 2.4 GHz would experience a shift of 625Hz. If the Doppler shift exceeded the frequency deviation tolerance of a protocol, or the frequency changed at a rate faster than the technology could accommodate, the data stream may not be correctly demodulated.

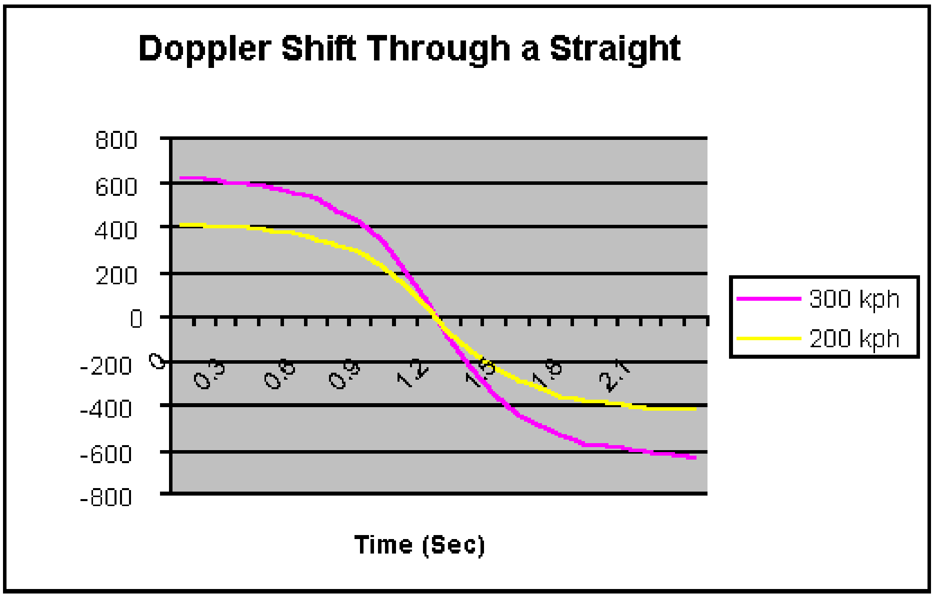

Figure 1 - Doppler Shift for the ISM Band

3.3 Opportunity Time vs Connection Time

In International motorsports events, cars can travel at speeds up to 340 kph with an average between 187 and 250 kph. Each track was essentially unique, so it was assumed that a car would travel through a straight track, chicane and a hairpin turn at 300, 130 and 70 km/h. This translated to speeds of 83.33, 36.11 and 19.44 m/s respectively. This research has defined the time that a vehicle was within a cell as the "opportunity time". Assuming a 100m radius cell, and using the pythagoras theorem and the equation of the perimeter of a circle, it was calculated that a car would travel through the straight, curve and chicane in 2.25, 7.45 and 8.22 seconds respectively. This is critical in selecting the correct technology, as a vehicle could have travelled in and out of a cell before the technology could establish a connection.

Track Scenario	Distance to Travel	Opportunity Time
Straight	187.34 m	2.25 sec
Chicane	340.48 m	7.45 sec
Hairpin turn	281.53 m	8.22 sec

Table 1 - Oportunity times for 100m Omni Cell

3.4 Handoff Latency

In cellular based architectures considerable delays can be experienced when a mobile terminal moves from one cell to another. In wireless networks this can be further complicated when the data is transported across a TCP/IP platform, as TCP assumed that bit error rates (BER) were negligible and confuses a temprarty loss of connection as cell congestion. Ludwig *et al.* found that the combination of these latency's could result in quite substantial delays of data and cell handoff resulting in delays up to 18 seconds *[Ludwig et al., 1999].*

4. Technology & Architecture Analysis

4.1 Technology and Protocol Analysis

To identify appropriate technologies for DAS application various current and emerging technologies was analysed using the OSI Reference Model. This is a generic structure that is composed of seven layers of which this research is only concerned with the first four layers. From this analysis, it was found that the General Packet Radio Service (GPRS), Multi-channel Multipoint Distribution Services (MMDS) and the IEEE 802.11 family of protocols were suitable for DAS Applications.

The physical layer is critical for the throughput of a network as well as the applications for which a technology could be used. From this analysis it was found that GSM and Code Division Multiple Access (CDMA) were two of few technologies that could accept rates of 21 kbps for data telemetry. When issues of Doppler and interference were considered, Bluetooth, HyperLAN/2, infrared and LMDS were all eliminated. This left 802.11, CDMA200, GPRS, MMDS and Wideband CDMA (W-CDMA) as viable technologies. CDMA2000, W-CDMA and GPRS required pre-existing infrastructure as the cost to build a network was significant. 802.11 protocols and MMDS could operate in the licence free bands of the Industrial, Scientific and Medical (ISM) band and Unlicensed National Information Infrastructure (U-NII) band, so they tended to be lest costly, but could experience interference.

The main task of the data link layer was to facilitate the transmission of data and to perform error detection and correction on the received data, before passing it on to the network layer. When the connection time of various technologies were investigated, results were not encouraging. Bluetooth, CDMA and GSM were the only technologies, which provided documentation about their connection time, which all exceeded two seconds. Multiple access capabilities were also studied, where GSM and CDMA were able to support up to 27 user, which is shared by both competitors and fans. For the 802.11 family of protocols up to six mobile terminals (MTs) could be sampled at 25 frames a second or above; when using the optional PCF, providing better capacity.

Security is an important function of the data link layer, where only HyperLAN/2 and, Local Multipoint Distribution Services (LMDS) provided acceptable security. 802.11 tended to suffer from passive attacks where encrypted streams were easily intercepted and decrypted. To overcome this, end-to-end encryption and other security strategies could be used. Also many researchers found that FEC performed better than ARQ for error detection/correction in real-time application like DAS networks. It was found that when the FEC was moved from the datalink layer to the network layer, the performance of the network using User Defined Protocol (UDP) experienced less packets loss and shorter delays.

The network layer is responsible for the establishment and clearing of network connections between two terminals. The major difficulties with operating Transmission Control Protocol/Internet Protocol (TCP/IP) over wireless network were the latencies and the lost data packets. As a result researchers have proposed variations of the IP, Mobile IP (MIP), Cellular IP (CIP) and Iterant IP. MIP was found to be incapable of handling real-time applications such as DAS networks, as there was trade off between the traffic overhead and the speed of handoff. CIP performed better as it provided semi soft-handoff capabilities, allowing a mobile node to connect to multiple BS during handoff, as long as they are all within range. IIP (an extension of MIP) significantly reduced the handoff delay *[Yap et al., 2000]* as it removed the need for encapsulation or to deal with triangular routing.

Yap *et al.* found that IIP performed better than MIP performing a handoff at the network layer in 870 ms and 69 ms respectively. CIP offers better performance than MIP, but not by much. To provide fast seamless handoff the Next Hop Handoff Protocols (NHHP) and Path Controlled Handoff (PCH) were developed. PCH was an intelligent handoff protocol that predicted the sequence in which an MT would require various APs. As motorsports events generally followed a racing track, it was an application that suited PCH.

The transport layer was the interface between the higher application-oriented layers and the network dependant protocols providing a message transfer facility that was independent of the underlaying network type, thus hiding the network from the session layer. UDP is more suited to DAS applications then TCP but requires, a transport layer independent protocol called RTP to provided lost packet and out-of-sequence packet detection, as well as efficient processing of the payload. To detect out-of-sequence packets as well as lost packets, RTP sent a sequence number with each packet. Also timestamps were transmitted as this enabled the receiving end to reconstruct the original timing before passing to the application layer.

4.2 Architectural Analysis

The three architectures that were identified as most suitable for data transmission in DAS applications were:

(i) *Overlaying GPRS on GSM*
This would have the same problems associated with GSM, but would have a greater throughput capacity. This was investigated as it was the natural extension of the current "Real-time and Burst" model.

(ii) *Broadband IP from an Aerial Platform*
Broadband wireless had been the focus of many researchers because of its high throughput and ability to support voice, data and video on the one link. There were three Broadband IP technologies that could be used, LMDS, Microwave Video Distribution Services (MVDS) and MMDS. For the aerial platform model, a hub was placed on an aircraft that was located at a distance up to 19,000 metres *[Banks 2000]* over the footprint that an ISP wished to cover. This system is very straightforward to set up and, once equipment was purchased (aircraft and trnascievers), relatively inexpensive to maintain *[Tozer & Grace 2001]*. For real-time data telemetry, this had potential latency issues, depending on the distance between the hub and the MSs.

(iii) *Remote Access Telemetry Environment (RATE)*

The RATE architecture was a proposed hybrid architecture composed of Access Points (AP), Data Collection Points (DCP), and a Central Distribution Centre (CDC). This is shown in Figure 2. Data telemetry was collected via the APs that were wired to a DCP. This reformatted and combined multiple data streams into a single high-speed data stream for transmission back to the CDC. The CDC read the data from the high speed pipeline and interrogated the data so that it could send it to the correct racing team. The CDC, and pit stops were all placed within an Intranet that was protected via firewalls. This also permitted limited data from each car to be transmitted to an external web site on the Internet, so that racing fans could monitor the progress of a favourite driver or team.

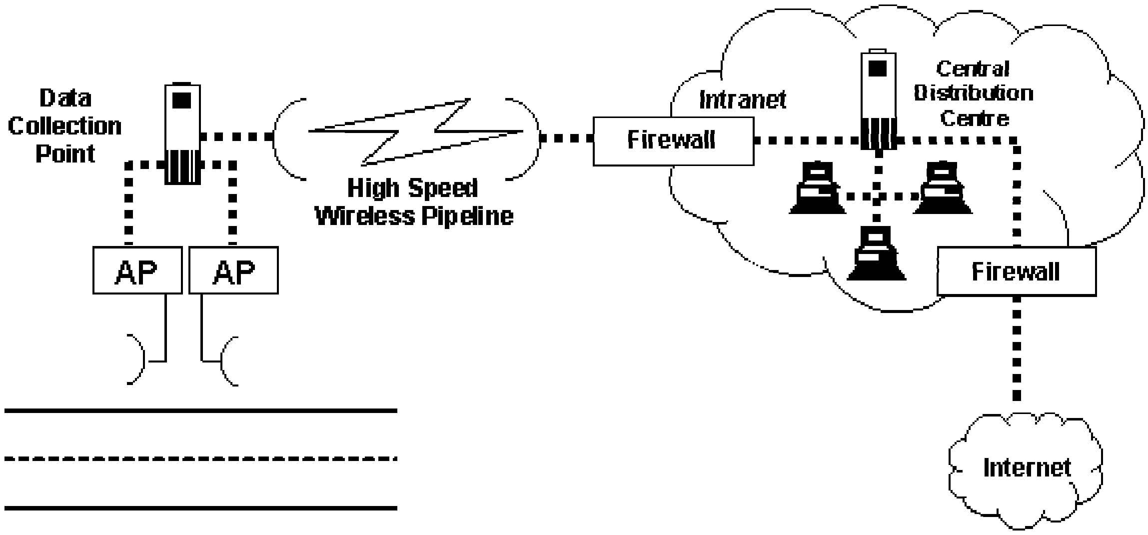

Figure 2 RATE Architecture

5. Conclusion

From the analysis of the different layers of the OSI reference model it was found that GPRS, MMDS and the IEEE 802.11 family of protocols warranted a further investigation for DAS applications. Also the GPRS and broadband IP (on an aerial platform) provided suitable architectures for motor racing based data telemetry. A Hybrid architecture called the Remote Access Telemetry Environment was also proposed.

6. Acknowledgements

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