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REGISTRAR AND
DEPUTY PRINCIPAL

OPTICAL FIBRE DISTRIBUTED ACCESS TRANSMISSION SYSTEMS (OFDATS)

VOLUME 1

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A thesis submitted for the degree of
Master of Engineering

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This thesis is
dedicated to

my wife Julia
and my children
Michael, Andrew & David

Without their support
this thesis could not have
eventuated

ABSTRACT

This thesis examines the design and development of distributed-access Backbone topologies and protocols for Integrated Services, Local Area Communications applications (both commercial and military). Optical fibre transmission media formed the basis for the investigation, this having a cost-effective bandwidth-distance product to suit the high-capacity, distributed-access requirements. A significant problem encountered was that of achieving a practical, cost-effective implementation, that was competitive against conventional PABXs and LANs. For Command & Control applications in particular, the need for extensive voice conferencing facilities, fast call-connect/disconnect response times, high reliability and surviveability were major areas to be addressed.

The investigation covers 8 years of research, breadboard, prototype and product development, targeted at networks serving a large number of low- to medium-capacity service channels. To this end, the investigation encompasses active optical fibre and mixed-media topologies and TDMA/SDMA access protocols. Both Dual-Bus and Dual-Ring architectures are addressed in detail.

Two main products emerged or are emerging from the abovementioned research, these being AWANET and MILNET. These products are both based on Dual-Ring technologies, and provide 1st and 2nd-generation capacities respectively. Compared to the Dual-Bus, the Dual-Ring topologies and protocols were found to be more efficient in terms of both capacity and hardware. As a result, the AWANET product proved to be successful against PABXs in Command & Control applications, while the MILNET product has yet to be evaluated in a competitive market.

Based on the experience drawn from the investigations into Dual-Ring and Dual-Bus technologies, the author concludes the thesis with a proposed universal network architecture called the Hybrid Ring-Bus. This architecture is shown to support the best features of both technologies, such as capacity/hardware efficiency and low transport delay. More importantly, the Hybrid Ring-Bus architecture is in principle, a perfect superset of the two forthcoming Local and Metropolitan Area Network standards, being ANSI FDDI-2 and IEEE DQDB/QPSX.

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A3 LOOP RECONFIGURATION OF BUS & TREE TYPE LOCAL AREA NETWORKS AWA RESEARCH REPORT R84-32

A4 OFDATS3 DESIGN CONSIDERATIONS - AWA RESEARCH REPORT R83-24

A5 OPTICAL LINK DESIGN & POWER/DISPERSION BUDGET ANALYSIS

A6 REGENERATIVE ETHER NETWORKS - AWA RESEARCH REPORT C86-11

A7 10B/12B LINE CODE DEVELOPMENT

A8 MILNET - MILITARISED INTEGRATED LOCAL NETWORK AWA RESEARCH REPORT C87-4

A9 HYBRID RING-BUS ISOCHRONOUS CHANNEL ACCESS PROTOCOLS FOR MILITARY APPLICATIONS - ANSI X3T9.5 FDDI-2 WORKING MEETING (Doc. No. 71), 30 SEP - 2 OCT 1987, ST PAUL MINNESOTA, USA

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CHAPTER 1

1. OFDATS PROJECT OVERVIEW

1.1 Introduction

In 1981, a Research and Development Project called OFDATS (an acronym for Optical Fibre Distributed Access Transmission System), was commenced by AWA Research Laboratory in Sydney, Australia (refer to Appendix A1). The aim of the project was to develop a Local Area Communications Network for Commercial and Military applications. Fundamental to the project were the requirements for distributed-access, integrated services and optical fibre transmission in a local area defined by private boundaries. The concurrence of these major requirements allowed considerable scope for originality in network design. In fact, the apparently successful network standard developments which followed, aimed at achieving these same or expanded objectives, did not formally commence until 1985 and were not finalised at the time of submission of this thesis. The standards referred to are the IEEE-802.6 Metropolitan Area Network (MAN) based on the DQDB/QPSX architecture [BUDR85], and the ANSI-X3T9.5 FDDI-2 Backbone Local Area Network (LAN) architecture [ROSS86].

Within the scope of this thesis, the evolution of the OFDATS research and development work toward meeting the above objectives, was undertaken in the absence of standards. The work passed through several phases of study, prototype and product development, culminating in a first generation product, called AWANET, and the first prototype of a second generation product called MILNET. An offshoot product which met all but the integrated services objective, was the OMM2 optical multi-drop modem. Beyond the scope of this thesis is the final MILNET product development, which due to the convergence of OFDATS research and the emerging ANSI/NOSC standards (Note 1), will be based on the FDDI-2 and US Navy SAFENET2 architectures respectively. However, early contributions to the MILNET design and the FDDI-2 Standard are covered by this thesis and will be discussed in Chapter 9. Finally, a proposal for a Universal Network Architecture which in principle, supports both the FDDI-2 & DQDB/QPSX protocols will be presented.

Note 1: ANSI is the American National Standards Institute,
NOSC is the US Naval Ocean Systems Centre.

Included in the remainder of this chapter is discussion regarding:

a. The scope of the thesis material,
b. The author's R & D contributions, and
c. The author's claims to originality associated with all phases of the Project up to the MILNET prototype development phase.

Subsequent chapters of the thesis then present the research material in detail.

1.2 Scope of Thesis Material

1.2.1 Local Area Communications Technology & Network Applications

To fully appreciate the design philosophy followed during the various phases of the OFDATS Project, Chapters 2 and 3 of this thesis will review the fundamental concepts and functions associated with local area communications, the commercial and military applications for which communications networking is required, the communications services which are required in these applications and the tradeoffs associated with the integration of these services within a single communication medium. The role and design objectives of the OFDATS-based products in the various local area communications applications will then be discussed as a precursor to the following Chapters on OFDATS Project evolution.

Much of the information presented in Chapters 2 & 3 was accrued by the author as Case Studies Group Leader for the Warren Centre Project on Local Area Networks & Office Automation [WARR83]. During the 4 month full-time involvement in this Project, the author worked under Dr John Limb, being the Project Director.

Additional information was subsequently accrued through application-related studies, design and installation experience associated with the Sydney Police Centre Radio Control System [HALG87/4], the RAAF Richmond/East-Sale and RAAF Tindal Air Traffic Control Systems, a RAN Ikara Data Bus Study, the RAN New Construction Submarine Project [HALG87/3], a distributed Process Control System for Queensland International Airport and the RAN New Generation Frigate Program.

1.2.2 OFDATS Project Research & Development Phases

The OFDATS Project commenced in March 1981 with a study phase, followed by several phases of design, breadboard development, prototype development and product development. The scope of this thesis covers the period up to December 1988, at which time a prototype implementation of the MILNET product was under development. To effectively illustrate the evolutionary development of the OFDATS Project, and the Network products which emerged, or were emerging from the Project, Figure 1.2-1 is included below as a reader's guide and reference.

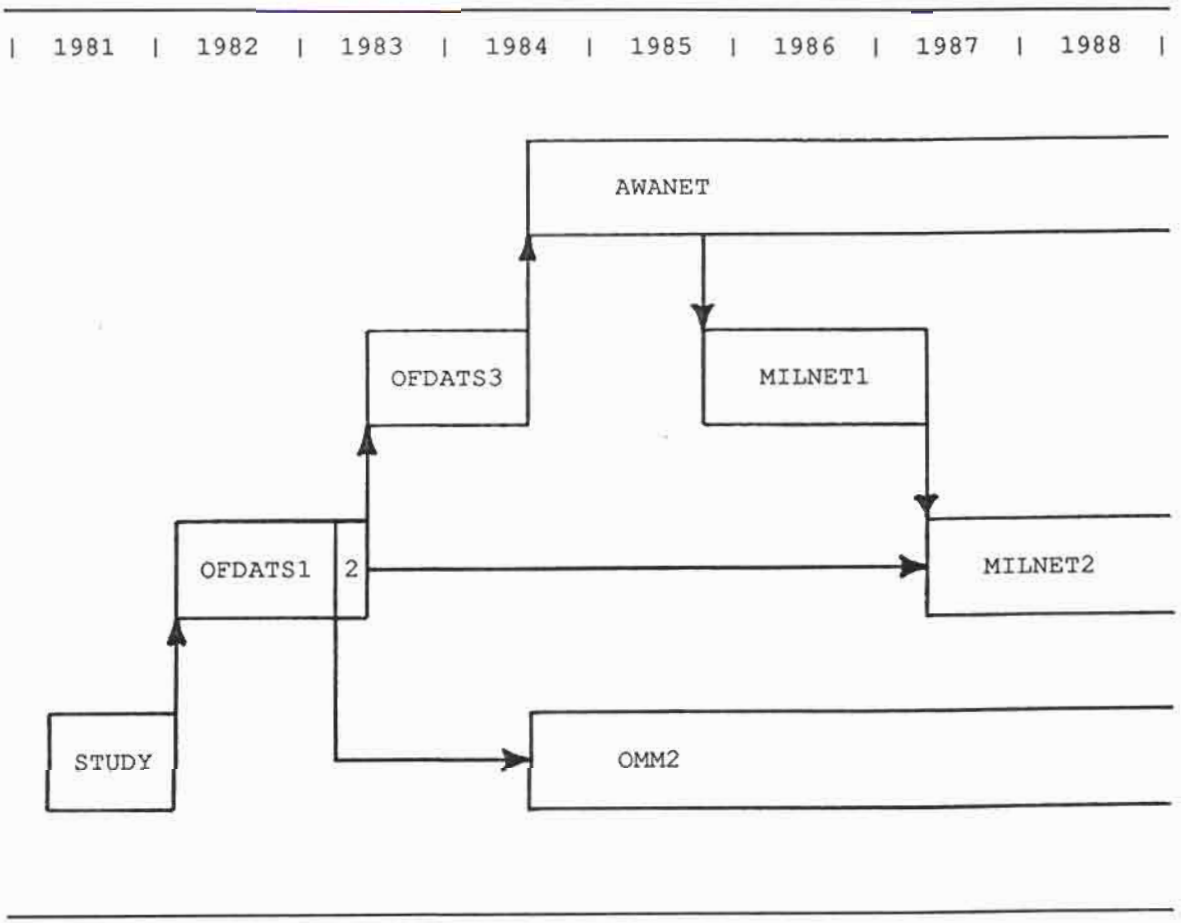

Figure 1.2-1 OFDATS Project Evolution

The various phases and evolution of the OFDATS project, including the subsequent AWANET/OMM2 product and MILNET prototype developments are discussed in detail in Chapters 4 - 9.

1.2.3 Conclusion to Thesis

Chapter 10 concludes the thesis with the following:

a. A Summary of all the OFDATS-related R & D Phases, and the key Network design features associated with these phases.

b. A list of Future Work yet to be undertaken and implemented (both within and outside the scope of FDDI-2 and DQDB/QPSX Standards), to further enhance the capabilities of Local Area Communications Networks in general, and Optical Fibre Networks in particular.

c. Key Conclusions to the thesis work, based on 8-years of application-related Network design, development and installation experience.

1.2.4 Appendices

In general, the thesis material which is not covered by external publications (refer to List of Publications & Reports), but is required to support the body of this thesis, is included in Appendices A1-A10. AWA Research Reports which are relevant to the thesis, but may not be readily accessible, have also been included in the Appendices.

1.3 Research and Development Contributions

Throughout the research and development phases of the OFDATS project, there has been joint research input from the author as a ME/Ph.D candidate, OFDATS Project Manager, MILNET1 Project Manager, System and Hardware designer, as well as input from other researchers and development engineers. In particular, during the first 3 years of the Project, the author worked under the guidance of Dr Jim Harvey, being the Project founder. As evidence of the author's project contribution, it is therefore necessary to identify the scope of research & development input and subsequently the claims to originality. With respect to the former, a list of R&D contributions is outlined as follows:

1.3.1 Study Phase

* Studied Burst-Mode TDMA Passive Optical Networks and Hybrid topologies in terms of Protocols, Timing Acquisition, Optical path losses, Receiver sensitivity, Link Dispersion and Node implementation. Also addressed the problems of WDM on fibre.
* Investigated the Frequency Acquisition behaviour of Phase Locked Loops using Sawtooth Phase Detectors and Multiplier Phase Detectors.

1.3.2 OFDATS1

* Studied 1st Generation Shipboard Data Bus designs.
* Investigated various Dual-Bus Network Reconfiguration and Node Bypass options for Shipboard Data Bus applications.
* Investigated various TDM Timing Structures and Communications Protocols for integrating voice and data.
* Investigated various combinations of Optical Transceiver, Line Code, Timing and Synchronization options.
* Analyzed the Drop/Insert Access timing in terms of mean/variance circuit delays - specified an appropriate timing arrangement for the User Interfaces to guarantee correct Slot-Access.
* Designed and developed breadboard model hardware to implement the Network Interface Unit - this included Optical Transceiver, Line Codec & Timing Recovery, Drop/Insert and Synchronization Boards.

1.3.3 OMM2

* Developed a technique for bridging between multiple Allen Bradley Data Highways using a Dual-Bus optical fibre backbone. The technique was subsequently referred to as a Regenerative Ether.
* Provided the preliminary hardware design for the OMM2 based on existing OFDATS1 NIU circuits.
* Specified the on-board implementation of the Optical Receiver to minimize the size and cost compared to OFDATS1.
* Assisted in the installation, testing and fault-finding of the OMM2 backbone at Queensland International Airport.

1.3.4 OFDATS2

* Re-evaluated TDM Timing Structures based on Word rather than Bit interleaving.
* Re-evaluated the Drop/Insert timing constraints.
* Re-evaluated the Line Coding and Timing recovery options, and their implications on the Transceiver design.
* Evaluated various centralised PABX Voice Conference Bridge designs for pending Air Traffic Control applications.
* Subsequently studied the application of the Instant Speaker Algorithm to distributed Networks, and its potential for Priority Voice Conferencing.
* Investigated alternative parallel-transmission options using electrical cables, aimed initially at intra-rack Node connections.

1.3.5 OFDATS3

* Studied the implementation of Hierarchical topologies using Dual-Ring Backbones and Single-Ring Clusters.
* Designed and analyzed a Distributed Power-Feed arrangement for use on Multipair cable, for small Cluster Ring applications.
* Adapted the TSI-based Elastic Buffer implementation (conceived by Dr Jim Harvey) to switch Interface Channels originating from the same Node (this was a Stubbed-Ring implementation requirement).
* For Ring-based Distributed Voice Conferencing, designed the "Tromboning-Bus" emulation and associated "Sidetone-Elimination" technique based on the Instant Speaker Algorithm.
* Designed the general construction and layout of the NIUs and CIUs for the Hierarchical Ring Network implementation. Provided the modified OFDATS1 Drop/Insert design for CIU implementation.
* Designed the Coding Rules and Software Development Environment for a 10B/12B Block Codec.
* Completed the detailed design of the NIU and associated 10B/12B Codec Board with Bit-Timing Recovery, Self-Heal Path Switching and RS422 Multipair Cable Interface.
* Undertook extensive EMI testing on the Multipair Cable option.
* Provided the preliminary hardware design for the Frame/Multiframe Synchronization Board.

* Translated the Broadband Coax. FDM Service Band concept to the TDM Frame Structure, as a meaningful approach to Slot allocation.
* Conceived an alternative Elastic Buffer/TSI design having different Multiframe Structures for each Slot, aimed at minimizing the Ring delay for each type of Service.
* Investigated alternative Triple-Ring topologies for Air Traffic Control applications.

1.3.6 AWANET

* Designed the general construction, layout, Access-Bus and Path Switching arrangement for the Dual-Ring CIU, to suit Alternate-Path and Self-Heal Reconfiguration.
* Designed the general construction, layout and majority-vote Monitor arrangement for the NCU.
* Specified the use of SDM/FDM Monitor & Alarm Channels, using the Regenerative Ether approach on the Monitor Channel, and Opto-Couplers on the Alarm Channel.
* Specified the provision of increased optical loss tolerance for the Monitor & Alarm Channels.
* Specified the segmentation of the Distributed Power Feed to guarantee power-up.
* Specified the use of the same Receiver implementation as for the OMM2.
* Specified the use of mated-pairs of Electrical/Optical Drop & Insert Boards to simplify the Mixed-Media implementation.
* Partially designed and specified the Backplane Voice Conferencing algorithm, and assisted in the testing of the algorithm.
* Conceived the use of Backplane Voice Conferencing for point-point intra-node communications using a single TDM Channel.
* Designed the mechanism for "Combining" Distributed Voice Conferences in Radio Control applications.
* Conceived the use of the TSI Switching capability to provide the "Conference Master" function for simpler Distributed Voice Conferencing.
* Conceived the use of the Multipair Cable option for old-building Riser-cable capacity upgrades.
* Designed the circuit for a Channel Test Board and a Multipair Cable Break-out Box for checking the integrity of the Network.

* Undertook extensive Clock-jitter testing and fault-finding of AWANET prior to installation in the Sydney Police Centre.
* Undertook extensive Backbone integrity testing, Voice Interface testing and fault-finding of AWANET during its commissioning in the Sydney Police Centre.

1.3.7 MILNET1

* Studied the application requirements of a Signaal Combat System for the New Construction Submarine Program.
* Adapted the AWANET design for low-risk implementation of the high-capacity, Triple-Bus (Dual-Ring) Network. Used the OFDATS1 experience to develop a surviveable Network design.
* Designed the use of dual Access Buses as a means of achieving Time/Space switching.
* Designed a specialised Word and Multiframe Timing Structure to suit the Signaal equipment. Subsequently modified the Word Structure for more general application.
* Specified the MILNET1 NIU and CIU construction and layout.
* Designed the means of achieving Interface cable access to all Buses in a Triple Bus Network.
* Conceived alternative Network configurations using the dual Access Bus approach. These included the Multi-Bus, OFDATS2 Dual-Bus, Dual-Ring and Hybrid Ring-Bus options.
* Conceived the mechanism for achieving accurate Global Time-Stamping on the Hybrid Ring-Bus option.
* Conceived the possibility of implementing a QPSX Distributed Queueing Packet protocol on the Hybrid Ring Bus option.
* Overviewed the construction and successful testing of the MILNET1 breadboard model Network.

1.3.8 MILNET2

* Studied the design of the FDDI-2 Network Topology, Reconfiguration, TDM Timing Structure, Packet Communication Protocol, Voice Communication Protocol options, Line Code, Timing Recovery, Optical Transceiver and Access Protocols.
* Subsequently, studied the implications of the FDDI-2 design on a Dual/Triple Access-Bus, Stubbed-Ring Node implementation.

* Designed the schematic implementation of a MILNET2 Node based on the provision of 3 Access Buses. Sufficient interconnectivity to the Backbone Rings was designed to permit the Hybrid Ring-Bus option to be implemented.
* Designed the schematic implementation of a single P-MAC Packet Multiplexer per Access Bus to avoid Stubbed-Ring contention.
* Designed the schematic implementation of the FDDI-2 Hybrid Ring Control Circuit so that accurate Global Time-Stamping could be implemented.
* Studied the application requirements of the Signaal Internal/External Communications System for New Generation Frigate Program.
* Assisted in the design of a Ring Cross Connect Reconfiguration option to reduce the cost of MILNET2 for the Frigate Program, while maintaining the required Network surviveability. Recognition is due to David Street for his prompting in this direction.
* Further evaluated the implementation of a Universal Network Architecture based on the Hybrid Ring-Bus option.

1.4 Claims to Originality

The following list of claims, highlights the author's most significant R&D contributions which have "original" content and thus represent a "contribution to knowledge" (the reader should refer to Section 1.3 for greater detail regarding the contributions):

* Using experimental techniques, it was determined that a Sawtooth Phase Detector has a Frequency Discriminator Characteristic. This was subsequently confirmed analytically with the assistance of Dr Ian Peterson and then published at [HALG82/2] and [HALG82/3].

* Independently conceived the use of the "Looped Dual-Bus" topology to overcome node and cable failures for OFDATS1. This was based on a previously published scheme which used a single optical switch [ITO81], and was subsequently presented at [HALG83/2].

* Independently conceived the "Regenerative Ether" Backbone concept for bridging between asynchronous, bit-serial Cluster networks (LANs) without preamble erosion and with low accumulated distortion and jitter [HALG86/2], [NORR87].

* Conceived a Distributed Priority Voice Conferencing Protocol based on a previously published centralised conference technique called the Instant Speaker Algorithm [PITR71]. The Protocol is in fact analogous to a Broadcast Packet Voice Channel, but with the advantage of having no overheads. A single 128 kbit/s Channel may be used with no significant noise build-up or distortion, irrespective of the number of conferencees. Until now, this has not been published in the literature (for proprietary advantage).

* Conceived a 30.72 Mbit/s Integrated Services, Distributed-Access Backbone Network that could be implemented at very low cost using Standard 25-pair Telephone cable and associated 50-way insulation displacement connectors (as an option to Optical Fibre cable). The 25-pair cable carried information, timing and network monitoring signals, as well as Distributed Power Feed Current to power adjacent Node regenerators in the event of an isolated power failure. This was published for the first time at [HALG85/1].

* Conceived the design of an efficient TDM Multiframe Structure for multiplexing Voice & Data Services. Subsequently adapted the Broadband Coax. "Service Band" concept as a more meaningful approach to Slot allocation and Packet/Circuit Bandwidth partitioning. This concept was first published at [HALG85/1].

* Conceived and designed the Coding Rules for a 10B/12B Block Codec, this being optimised for the AWANET implementation. The 10B/12B Codec design was subsequently published at [HALG85/3].

* Conceived the application of a TSI-based Elastic Buffer for the switching of TDM-Ring Channels. This was an implementation dependent requirement due to the Stubbed-Ring approach used in the OFDATS-based designs. The technique was published at [DANG87].

* Conceived a Universal Network Architecture called the "Hybrid Ring-Bus" which is in principle a perfect superset of the two emerging DQDB/QPSX and FDDI-2 Network Standards. Also conceived an accurate Global Time-Stamping technique that could be used with the Hybrid Ring-Bus. This was first presented at [HALG87/5]. Subsequently, joint-conceived the Ring Cross Connect function.