Low Cost ATM and The ATM Warren

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Abstract

The full version of this paper introduces the concept of the 'ATM Warren'*. The Warren is a subnetwork of an ATM network composed of an arbitrary mesh of very simple ATM switches and end stations and which is connected to the outside ATM network at one or more points. The novel aspect is switches and end stations within the Warren are designed to be implemented entirely in hardware with all control software banished to computers outside the Warren.*

Keywords: VOD, ATM, HAN.

1 Introduction

The cost of Asynchronous Transfer Mode technology is falling while its deployment is growing. Once regarded as a technology strictly for rates above 100 Mbps, ATM may now be considered for any networking scenario where multimedia and real-time are important. The authors were of the first proponents of private ATM networks [GM01, GM02] and have subsequently seen the growth of ATM LANs in the workplace for applications such as video-mail and desk-top conferencing. In this paper, we look at a possible deployment path for ATM technology in the home. This is based on dumb ATM devices which can be built for low cost. The style of operation and method of control of these dumb devices uses the approach of the *ATM Warren*. This paper introduces the Warren.

1.1 Justification and Trends

Video-on-demand trials using ATM subscriber links are now starting, and there is no better example than the Cambridge Interactive Television Trial [GV95]. Earlier trials may have used ATM in the core of the network, but terminated AAL1 circuit emulation before entry to the home, so that the home is fed with a fairly inflexible structure, such as a single continuous MPEG multiplex transport stream. Although this is still one of the options recognised by DAVIC in their set of reference configurations [DA95], most people recognise that there will be multiple devices in the home which require outside service connections and a more general-purpose network is required. This must support multiple streams to the home, allow communication between devices in the home and be able to support considerable bandwidth out of the home in the future. The Cambridge iTV Trial offers each home an ATM Forum compliant UNI [AF94] which may either be directly connected to the first home set-top box, or else connected to a consumer ATM switch which forms part of the Home Area Network [HAN]. By *UNI-compliant* we mean that the cell format, traffic contract, signalling and operations and maintenance procedures defined by the ATM Forum are followed. This implies that any vendor's current generation ATM equipment may, in principle, be plugged in and expected to work. For instance, for homeworking, a PC with identical software and ATM line interface card to the one used at someone's office can be used at home.[1]

1.2 Residential ATM

The advent of a new wall socket in the home giving wide area access at reasonable bandwidths, even though it be only for video-on-demand applications in the first instance, is an important seed towards establishing data outlets in every room in the house. In effect, we are following the model which has deployed residential POTS phone service over the last half century.

In our contribution to the ATM Forum [AFCA] we recommended the following Baseline Criteria for a *Homepoint*. The Homepoint is a point of attachement to the outside world offered by the residential access network provider into which a consumer can plug either a single piece of ATM equipment or else a link to a privately-owned

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[1] In practice, nameservers, IP and ATM addresses and access rights may have to be modified.

ATM switch. Standardisation of the Homepoint is seen as important in the future, to enable multivendor supply of STBs and other devices.

The Homepoint is offered on a network terminator (NT) unit at the point of entry to the home. It is the contractual boundary for the wide-area network service and the boundary between privately owned, domestic equipment and the service provider's equipment. The NT provides network protection and management functions, including electrical isolation, source-rate policing, admission control and tariffing support.

The contribution further offered baseline criteria that all residential ATM solutions should adopt:

- **A Single Connector.** A single connector must be defined which can support digital cable television, including VoD, hifi, security, computer home working and all other network applications.

- **Standard ATM Forum UNI available in the home.** Residential ATM should conform to the same basic specifications as ATM LANs. These specifications cover the physical layer, signalling and management. This provision enables equipment sold for the office to be used at home and vice versa.

- **Access Method Independence.** The wiring and protocols within the home should not depend on the media technology used to bring ATM to/from the home (e.g. PONS, Coax, Radio, ADSL). The Homepoint connector operates at one standard rate only. Cell-rate adaption is implemented behind the Homepoint in the NT to match the standard rate to the rate(s) provided by the metropolitan area medium.

- **Bidirectional and Symmetric.** The Homepoint should be bidirectional with symmetric bandwidth for receive and transmit. Most installed homes in practice will have asymmetric wide-area provision, but admission control and cell-rate adaption should be used to restrict the outgoing traffic, rather than reduced physical rates at the Homepoint connector. All installations should provide for upgrade to symmetric bandwidths on a per-home basis.

- **Switchable.** The system should enable miniature, domestic ATM switches to be installed at any point to fan-out the ATM network within the home.

- **Proxy Control Service.** Small ATM objects in the home will not support the full ATM signalling stack themselves and will instead rely on proxy control. This requires additional permanent virtual circuits to be configured within the residential ATM system to carry the control messages between the proxy and the device. The proxy can either be located in the home and operated privately or, for entry level systems, be provided over the access network as a customer value-added service.

An important contender for the physical realisation of the homepoint is ATM25 [AC94]. This is a low cost ATM link technology which can run up to 100 metres on low grade twisted pair using RJ45 connectors. The practical work for the Warren Project is using this format. ATM25 may also be run over CATV coax and plastic optical fibre (POF). However, whatever the preferred media and outlet format, the important aspect is that a standardised physical layer is emerging within the home into which people expect to plug devices.

The major problem with current ATM protocols is that the switches and end stations are all expected to support vast quantities of signalling and management software, including a base set consisting of Q.2931, SSCOP and SNMP. For a large class of possible ATM devices (including for instance an infra-red base station) the RAM and processor required to implement these protocols is more expensive than the sum of the cost of the actual data handling components, including the AAL and line interface.

Instead of trying to define alternative *lightweight* versions of these protocols, the approach of the Warren will be to remove all of the software from both switches and endstations and locate it in one controller computer, where sharing of code space and other resources is possible.

1.3 Technology Seeds in the Home

We have established that an ATM service to the home is a likely future norm. For ATM technology to dominate within the home in the Home Area Network there needs to be one or several further seeding routes which will introduce a diversity of ATM devices to the home. We also require that a Home Area Network can operate without connection to the outside world, or even with multiple diverse outside connections. In this section we present our view of where these seeds will come from. The subsequent sections of the paper show how the *ATM Warren* architecture enables low cost implementation.

Our principal approach is to convince designers that the on-cost of ATM[2] can be low and to assume vertical seed application markets where ATM has been deployed either with a view to future applications or because ATM is as least as good as the 'current solution'. Actually, situations where there is a 'current solution' are adverse owing to the evolutionary need to simultaneously support the old and

[2] By 'on-cost' we mean the increased cost of the basic version of a product in order to support future expansion. In typical consumer goods markets, this must be limited to a very few percent.

	Transmit	Receive
SP-DIF (no subcode)	740 (28)	1027 (78)
ATM AAL0	774 (57)	1024 (83)

Table 1: Two input gate counts for SP-DIF and ATM line interfaces. The value in parenthesis is the number of flip-flops: these are counted as 6 gates in the main figure.

the new on bridging products. The best seeds for ATM are where products are not yet at commodity production levels; examples are home theatre, video-on-demand and multi-room HiFi.

1.4 Home Applications

A method for ATM devices to penetrate the home is the replacement of existing point-to-point interconnection systems with point-to-point ATM using hardwired VCIs. For instance, SP-DIF, the digital interconnect for stereo HiFi found on CD and DAT players and home theatre goods is a prime candidate [GG95]. The figures in table 1 show the actual gate counts required in two alternative implementations of a digital link: one SP-DIF and the other ATM. The difference in gate counts is not great, but the ATM version has the benefit that an ATM switch can inserted in series with the link to enable the streams to be freely switched and routed. To be fair on SP-DIF, it is likely that additional playout RAM will have to be added to the ATM implementation, to take into account that SP-DIF has jitter expectations of nanoseconds and playout buffers of order one sample, whereas ATM will need playout buffers of order one cell. However, we assert that the benefits of not having to use a specially designed SP-DIF switch together with the increased flexibility of ATM ameliorate the cost penalty.

Another seed for ATM is enhanced convergence of already converging technologies. In the office market, we see the convergence of the PC with the phone since this reduces wiring and helps greatly with the following: diary, dialing, directory, wiring and audit. In the home we see convergence of TV and Hifi and the future convergence with multi-room and home theatre. Given that all of these devices have a chance of being implemented using ATM, we see a potential knock-on benefit in the form of new applications which integrate the components in various ways, such as using the HiFi speakers for PC sound output or using the PC screen for indexing of a Video or CD collection. We will also see the desire to add other home electronic components to the system, such as baby monitors, doorbells, heating control and security components.

The fact that a wide-area connection to the home is also provided enables applications such as answering the front door when at work and checking the security of the home when on holiday.

Another class of applications is remote monitoring and control of homes. Remote meter reading is always a good candidate - not just mains resources, but also TV viewing figures are metered in some homes. There is also a class of protected housing for old people and so on where room temperature and general activity monitoring is provided even today over POTS. It is our hope that a few mainstream ATM seeds, such as video-on-demand will spawn similar vertical applications and finally there will be full convergence through diffusion.

A final benefit of integration is the reduction in the total number of peripherals and processors. Instead of separate loudspeakers in each of the answering machine, the TV, the HiFi, the doorbell and the baby monitor, one can be used. This is especially useful if one often wears headphones.

To summarise our assumptions, we see that the home-area network will use have a prevalant physical wiring standard which all new consumer equipment is built to and that media and technology adaptors are readily available for legacy systems. These adaptors will convert from formats such as analogue HiFi, digital HiFi, RS232, infra-red to ATM. At the same time, designers of consumer products and the chips which go in them will start using a hardwired ATM port for any form of digital IO. This will spawn a whole new genre of home applications.

There will remain a class of very low cost devices which do not warrant upgrading to ATM. This includes existing devices and devices where ATM would be used only for control. The use of mains signalling such as Celtel's X10 Home Automation Signalling [CT95] and emerging European Home System (EHS) devices is likely to continue, but with the addition of a simple ATM to mains gateway. However we would argue that the principle benefit of mains signalling is a wiring issue and the cost of an ATM codec would be cheaper than the RF codec.

Radio is another important technology, but we believe that copper or POF solutions will be predominant in the home, mainly for bandwidth and security reasons.

2 The ATM Warren

The *ATM Warren* is one approach to building a low cost ATM network suitable for residential use. The Warren enables a new class of low complexity Warren switches and endstations, while still preserving the multi-media benefits of ATM and full interoperability with ATM standards.

The Warren is an ATM subnetwork comprising an arbitrarily interconnected mesh of simple ATM switches and end stations, as shown in Figure 1. Both the switches and

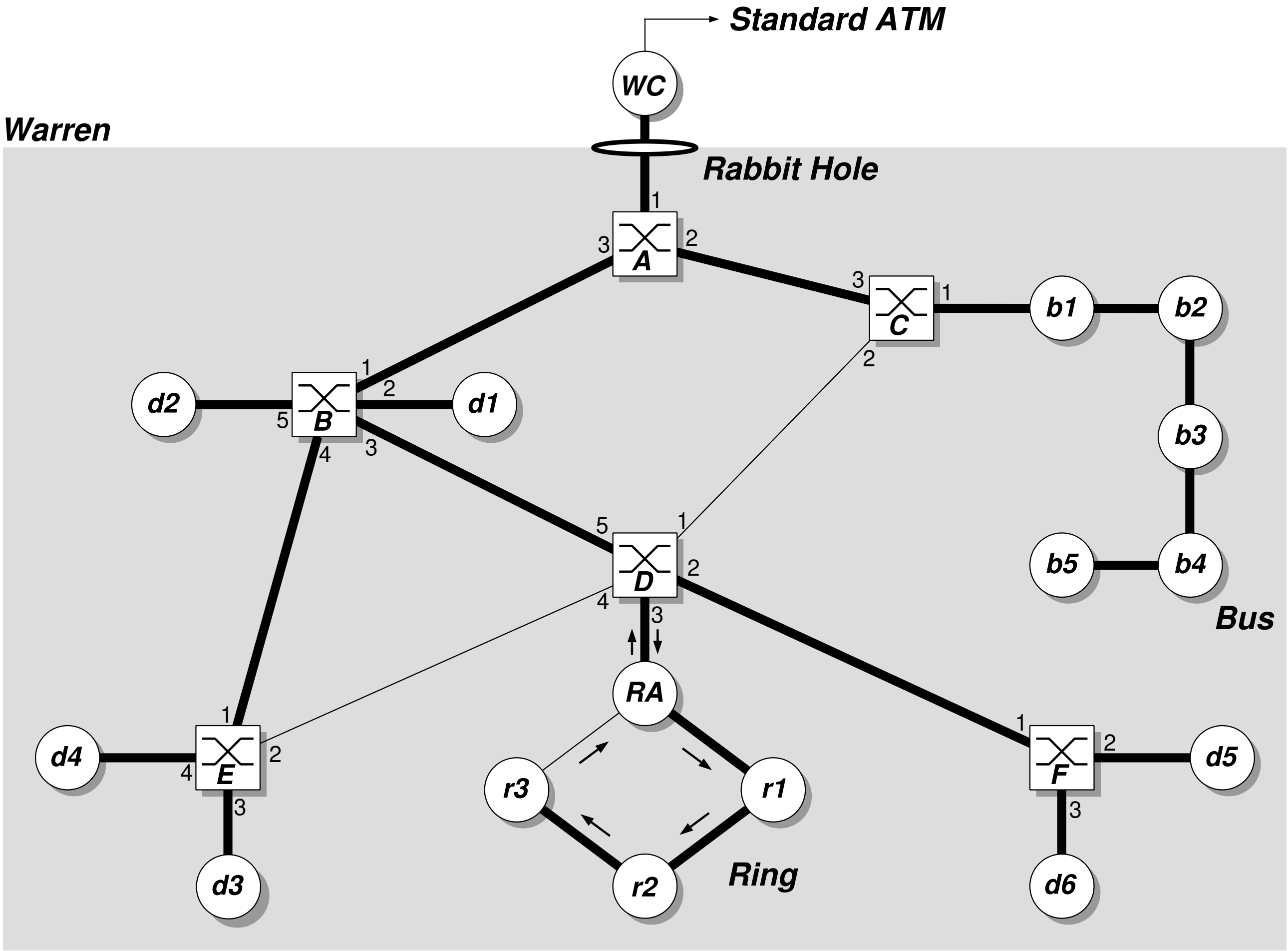

Figure 1: An example Warren with superimposed spanning tree

the end stations are designed in such a way as to be implementable entirely in hardware – i.e. they require no microprocessors for signalling and management. The signalling software for all the devices within the Warren is provided by proxy servers. These proxy servers are software entities situated on one or more general-purpose computers connected to the external ATM network outside the Warren.

The Warren provides the full set of normal in-band ATM semantics as defined in ITU recommendation I.361. VCCs (virtual circuit connections) originating, terminating, or passing through a Warren behave like any other ATM VCC.

Another key aspect of the Warren protocols is that a certain amount of point-to-point ATM communication is possible without any control or management. Point-to-point connection establishment can be achieved simply by plugging a pair of end devices together. This is because a Warren transmitter and receiver expect to use a fixed hard-wired VCI value for each type of stream, whether it be for data or control. For instance, a future ATM video recorder could be directly connected to a future ATM television with a point-to-point Warren link and no software involvement. However, later on, the owner of these consumer durables may wish to expand his home entertainment centre by introducing a low cost ATM switch: for example, to attach an ATM video camera and a second ATM television in a remote room. Using the Warren approach, no modification to the ATM implementation or configuration within these pieces of equipment would be required to do this.

2.1 Warren Extent and Control

In the Warren, the ATM plane function normally known as 'Management' is provided by the *Warren Control Protocol*. This also provides the equivalent of the ATM plane function known as 'Signalling' for dumb devices. Standard ATM devices that happen to be connected to a Warren can use conventional signalling through the network to a signalling agency or proxy provided alongside the Warren.

The Warren is composed of special switches which implement Warren protocols. A group of interconnected Warren Switches, together with a Warren Controller and the leaf Warren end stations, defines the extent of a Warren.

The Warren switches operate as standard ATM cell switches, but have a simple standardised architecture which can easily be monitored and controlled externally using single cell messages which from part of the Warren Control Protocol (WPC). Each switch has a designated *Up Port* which points towards the outside world. The choice of up port for a given switch is not hardwired into the device; rather the Warren executes a distributed topology determination algorithm at power-up time.

The switch at the top of the Warren (switch *A* in the figure) is special in the sense that its up port is not connected to another Warren switch, but instead to an external controller known as the *Warren Controller (WC)*. The WC may actually be situated several hops away over a further mesh of conventional ATM switches (e.g. perhaps in the central office of a town). The point of exit to conventional ATM is termed the *Principle Rabbit Hole (PRH)*. Other conventional ATM networks could conceivably hang off other switch ports the Warren, to form other RHs, but the Warren has exactly one PWC connected to exactly one active WC.

At least three types of proxy are needed for operation of the Warren as an ATM network. These are

- The Warren Controller (WC) which looks after the switches.
- Proxies for the Warren end stations.
- Proxy signalling agents for each switch, to allow non-Warren ATM devices to be attached to a Warren switch without modification.

The WC could consist of a Linux PC without screen or keyboard, but likely with PCMCIA slots. Any equivalent multitasking processor with loadable software modules and an ATM interface will serve. The WC serves a number of purposes:

- It has complete knowledge of the Warren topology which enables it to set up connections on behalf of Warren end stations.
- It maintains a mirror of the contents of the routing table of each Warren switch and full information about VCI and VPI allocation on each link.
- It serves as the reflector for crosslink control cells.
- It behaves as a gateway between the ATM Warren and other standard ATM networks, such as the Homepoint already described. This enables interworking between Warren devices and full ATM.
- It behaves as a security firewall, protecting Warren devices from external unauthorised access.

For each device in the Warren, there is a proxy signalling and control agent which is a software entity running on a computer outside the Warren. This computer could be the same computer as the Warren Controller, but then would typically be a separate software module or process. A device proxy controller may manage only one device, a set of devices, or all devices of a given type in one Warren.

Normal ATM devices will have their signalling requirements served through a collection of PVCs to signalling agents running on machines outside the Warren. The signalling agents perform the functions expected inside an intelligent ATM switch and communicate to the Warren Controller in order to actually establish the VCs set up by such signalling.

The Warren design also allows for the use of more varied physical network topologies. The figure shows examples of both bus and ring structures attached to Warren switches. These represent a valuable economy in the number of switch ports used for a modest increase in complexity of the end stations.

3 Further Reducing the cost & Multiaccess

The Warren achieves its low complexity using simple end stations, switches with no software and proxies for everything. Within the Warren architecture, we plan to evaluate a number of variations which further reduce complexity.

3.1 Simpler Still Stations - Simplex

A major way to reduce the cost of an ATM-attached device is to restrict it to simplex operation: some devices need only to be able to transmit data (e.g. a microphone) while others need only to be able to receive data (e.g. a loudspeaker). In the home environment or for general spatio-locality based control, it is often desirable to have an infrared input or output from a Warren device, and so we may choose to fit an infrared input to modules which only have ATM output and infrared output to those which only have ATM input.

3.2 Reducing the Number of Switch Ports Required using Daisy Chaining

The incremental cost of providing a ‘through’ ATM port on a a module which is nominally a simplex receiving ATM module is low. A through port is an ATM simplex output which can connect to the input port of another instance of the same (or a similar) module. In this way a daisy chain of output devices can be created allowing sharing of a switch port. A typical example might be a set of stereo or surround sound loudspeakers.

The key to the low cost of the through port is that it is connected to the module’s input port at a low level with no switching or buffering of cells. Therefore no FIFO queues are required for it and for every cell received on the module’s input port, one is repeated on the through port.

In order to separately address multiple modules in a daisy chain it is necessary either for them to be selective in which VCPIs they respond to (which implies that they are programmable or programmed in some way) or else for the through port to slightly modify the cell header of each cell it forwards. In order to address multiple identical devices in a daisy chain, algebraic manipulation of VCI values in the cell header of cells is a simple solution. The simplest manipulation is to subtract a number, such as 32, from the VCI of each cell forwarded. This is what we do in the Warren loudspeaker.

3.3 Slotted bus topologies

The wiring within the Warren may either use conventional ATM point-to-point links, such as the ATM25 standard, or it may use multi-access, slotted busses or rings. Conventional links, like ATM25, can be used as part of a multi-access slotted bus, provided that a ‘head-end’ generates a continuous stream of empty cell slots with VCPI set to zero, and stations with cells to transmit only overwrite empty cell slots. Receiving stations can perform filtering based on VPI masks. Providing fairness or other load-balancing between contending transmitters can be done using call admission control and/or any of the conventional techniques [GW92]. The stations connected to such a shared media operate within a common VCPI space.

The appendix to this paper describes an access protocol known as the Token Tagging Ring, which enables any ATM switch port to become the controller for an ATM slotted bus.

4 Upper Layers

In-band data flowing in and through the Warren is not restricted in its choice of adaptation layers, since the standardised ATM layer service is available[3], and so the accepted protocol stacks may be used, such as TCP over IP over AAL5 over ABR over ATM. However, in a low cost ATM system it is worthwhile defining alternative adaptation layers which can perform valuable functions yet which are simple enough to implement in hardware. Examples include audio, infra-red, button pushes and reliable data.

4.1 Warren Infra-red Protocol (W-IRP)

The Warren Infra-red protocol is used to relay infra-red commands from or to an ATM infra-red basestation, over the ATM network, to or from a processing agent running on a computer. The computer is outside the Warren (by definition), and may actually be the same processor as used for the Warren Controller.

The Infra-red Protocol uses single cell messages to carry a compressed form of the sequence of ‘needle’ pulses used by infra-red systems and is therefore adaptable to a variety of consumer infra-red formats.

A variation on the infra-red protocol is used for button pushes from an ATM control panel or doorbell.

4.2 Warren Byte Stream Protocol (W-BSP)

The Warren Byte Stream Protocol (W-BSP) is a protocol designed to be implemented in hardware. It reliably conveys a byte stream for applications such as MIDI (musical instrument digital interface) and Centronix(C) parallel port,. or RS232 link emulation. W-BSP carries one byte of data per cell and does not require the end station to be able to read or write the last 24 bytes of any cell. This eases hardware implementation, but limits the user bandwidth to a few hundred kilobits per second.

Although TCP is the dominant transport protocol for data networks today, there are many applications with reliable communications requirements which are of sufficiently low rate yet still require low end-to-end delay that using only one byte per cell for data is acceptable. Actually, the efficiency of TCP/IP/AAL5/ABR/ATM for these applications is not dissimilar. A gateway process running on a proxy is able to convert to and from W-BSP to the more normal TCP/IP/AAL5/ABR stack.

4.3 Warren Audio Protocols

One way to carry audio is to encapsulate SP-DIF over AAL-1. Another way, currently used by the Warren audio devices, is to simply alternate left and right channel sixteen-bit samples throughout the cell, resulting in 12 samples per

[3]The ATM layer service is nothing more than ordered delivery of ATM cell payloads over a VC.

cell. For mono sources, such as a hand-held microphone and the baby monitors, every other sample is zero, giving 6 samples per cell. Another possibility would be to use the first word of the cell as a type identifier to indicate the number of samples per cell, sample rate and sample precision, and drop to 11 samples per cell. The increase in hardware complexity at the source and destination is only small, since a cheap mask ROM can be introduced for the transmit side and simple pattern matching can be used at the receive end. Currently, we are using all of these methods and are not sure yet which is best. A good solution will enable flexible grooming of stereo and multichannel pairs and support speaker phase synchronisation.

5 Conclusion

In the full version of this paper a general approach and control protocol for a low cost ATM networking system is described, where software may be concentrated at a single controller. This reduces the complexity required in an ATM switch or attached device to the point where making an ATM version of a consumer HiFi or Video component is little greater than existing non-ATM solutions.

Ongoing work is implementing the ideas presented. So far we have microphones, loudspeakers a CD player and baby monitors all using the Warren end station protocol. We are using a software overlay on existing switches (ATML Viratas) to emulate the Warren switches. In the future we will build Warren switches and other devices, such as doorbells, infra-red basestations and mains controllers. In a related project, the HAN Project, we are designing a simple and easy to manage home naming and application control architecture in order to utilise the basic ATM VCs provided by the Warren.

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