A Different View of the Home Network

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Abstract. The current favourites for a high-speed digital network for video and other applications in the home are ATM, Ethernet, and IEEE 1394 Serial Bus, none of which was designed for the application. This paper considers the requirements of a network for the home, and proposes a communications system to meet those needs. The result is a system which sends data only along wires that are necessary for the connection, which conserves power and RFI emissions by taking wires quiescent when they have no traffic, and which allows the complete freedom of topology necessary for the untrained users in the home. While using the Data/Strobe encoding and link-level protocols of IEEE 1355 links, it both simplifies and extends these protocols to provide simple AC-coupled physical connections (PHY), to provide multicast and priority as well as unicast routing, and to integrate power supply and a low-speed control network on the same wires as the links. Compared with a home network based on IEEE 1394 or Ethernet, the network offers dramatic reduction in the required cable bandwidth. Compared with a home network based on ATM, the network is exceptionally simple.

1. Home Networks

There is currently a great deal of activity in attempting to standardise the technology used in home networks, particularly for digital video, but also for control of heating and ventilation, and for security alarms. At present, homes tend to be wired with many different networks, none of which can talk to each other, for example telephone, TV antenna, Cable TV, security alarm, central heating controls, quite apart from the mains power wiring.

Particular candidates for the home video network are ATM [6], which was designed for a global telecommunications network, IEEE 1394 [7], which was designed as a desk-top network for PCs, and Ethernet, which was designed as an office network without any concept of real-time.

A proposal to several of the standardisation committees was IHDEN [2], an In Home Digital Entertainment Network, which was based on IEEE 1355 [1]. While not originally accepted by the standards committees, it showed that 1355 has much to commend it for the application. The authors have examined both the application and the strengths and weaknesses of 1355, and propose a solution which builds on the strengths of 1355.

Particular emphasis has been put on integration of all the aspects of the home network, on tolerance of untrained users, on minimising the cost of routing switches, and on environmental aspects of the network.

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2. Complete home-wiring system

Figure 1 shows the outline of a home-wiring system. The routing switch and batteries (DC-UPS) would be in a closet, and would each connect via one or more cables to each room. Within each room, equipments might be connected individually to a wall socket, or in a ring or other network, or be themselves connected by another routing switch and maybe separate power supply and DC-UPS.

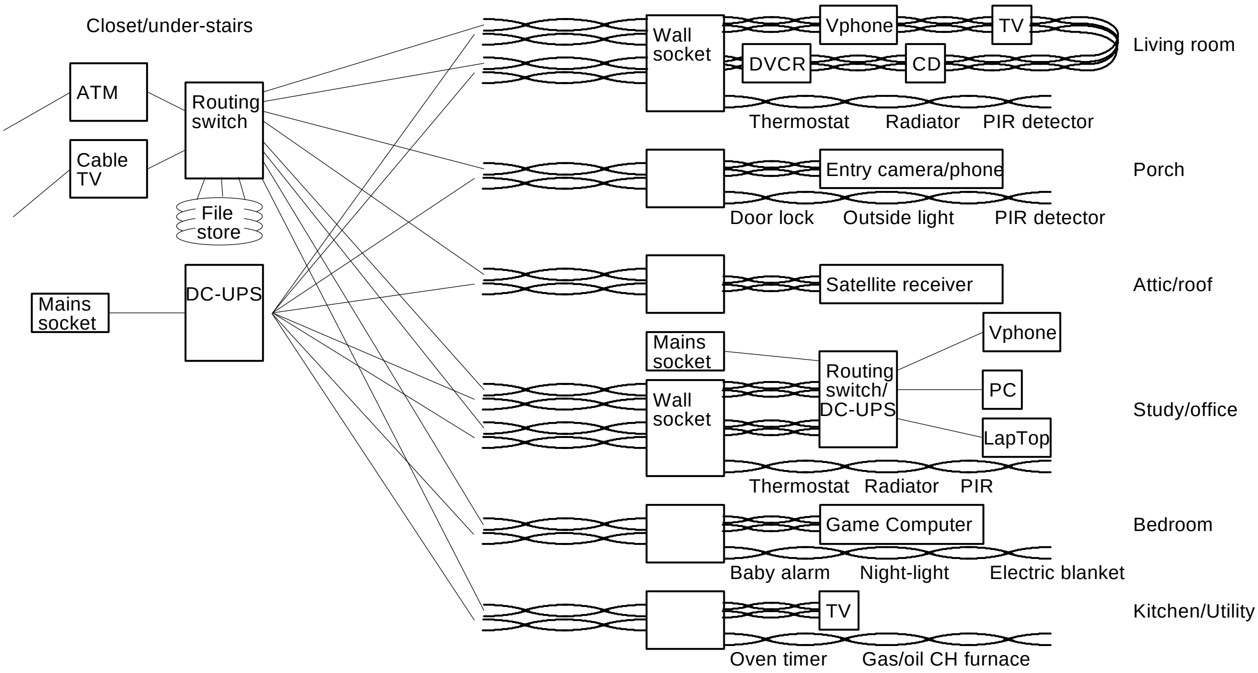

Figure 1: Outline diagram of complete home-wiring system

Some key points are shown up by the network of Figure 1

- It supports not only video and high-speed data, but also very low-speed signalling for humble things like solenoid valves and light switches, otherwise we'll just have a continuation of the current plethora of different networks (TV antennae, phone, burglar alarm, central heating controls, ...)
- Power supply is fully integrated, and backed up because we will become dependent on the network particularly in emergencies such as power cuts.
- There is a variety of different clusters, with external network terminations (Cable TV, Satellite and ATM) usually remote from the clusters. It is important that traffic on one cluster does not interfere with traffic on another cluster.
- There are many ports on the network, some of which are only rarely active. It would at least be highly desirable if minimal power was used when a port was inactive, rather than run the whole network all the time at full power.
- The network is topologically varied, with multiple starred hubs, loops and unlooped strings. Topological flexibility is particularly important in the home where anything might be plugged into anything, and it needs to work.
- Installation and modifications will be done by unskilled people, and so the network must be tolerant of wiring errors, particularly of twists in cables.
- The network is used for security, and so must be tamperproof, or at least able to detect that tampering has occurred

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- The protocols should be safe, and not allow a rogue computer somewhere in the network (or a hacker) to write all over the address space of another processor, particularly if the other processor is in a different cluster.

3. Data-rates in different parts of the network

Figure 1 is drawn as an example of the sorts of configurations that might be used, but we can expect there will be more clusters in many homes and perhaps four clusters is a reasonable number to design for. The data-rates required depend dramatically on the logical topology of the network and whether is uses repeaters or switches/bridges.

If we assume that the data-rate required on each cluster is around 100Mbits/s half duplex, and we use repeaters, there are two choices. We can either keep the whole system bandwidth at 100Mbits/s half duplex, in which case each cluster will actually only be getting 25Mbits/s for itself, while the other clusters are getting the remainder. Or we can boost the whole network to 400Mbits/s half duplex, when each cluster will get its 100Mbits/s.

If we connect the clusters to a switch or a bridge, then the amount of traffic actually going between two clusters must be less than the traffic on each of the two clusters. So if each cluster is running at 100Mbits/s, then adequate performance would probably be gained by connecting to the switch/bridge at 50Mbits/s or so.

The difference in required performance between repeaters and switches might not be quite as much as the order of magnitude suggested here, but it must be recognised that there is a significant difference and that the requirements placed both on the PHY and on the switching/bridging mechanism is dramatically affected by this choice.

4Links and Keele have taken the choice of using a switch, and to use a cable data rate of 50Mbits/s full-duplex on two pairs of a cable. Some rooms, maybe all rooms, would receive two of these pairs of pairs to give 100Mbits/s full-duplex to each room, which should be more than enough to support the cluster in each room. A switch with multiple ports, each at 50Mbits/s full duplex, gives a total system data rate of several Gbits/s — a data rate much more easily handled on a single silicon chip than on every wire in the house.

4. Design for a cost-effective switch

A switch is undoubtedly more complex than a repeater, even if the repeater means much higher data rates on each wire, and so a choice of switching protocol must be taken to minimise the switch cost. The IEEE 1355 protocols have been shown to be particularly effective for switches, with the interval labelled C104 [9] from SGS having 32 serial ports.

The routing protocol for the C104 switch is ideal for some applications, but needs rather more memory and logic for its interval labelling and routing than is ideal for a home network. Also the absence of multicast in the C104 is a disadvantage for the home network. We propose a routing protocol, therefore, which is optimised for the home.

The simplest routing protocol is physical routing, used in the ICR C416 [8] routing switch for the T4xx family of transputer links. The ICR C416 uses the first byte of the header to select the output port at each switch, and this byte of header is stripped as the packet is forwarded to the next switch. In the home network the number of switches a

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packet needs to transit is unlikely to be more than four to six, and a header of four to six bytes is acceptable.

For multicast, there is a limited number of multicast channels in a home and all the routing switches can be set up for the same channels. The resulting packet format is shown in Table 1. The Channel Identifier byte in the Unicast case is the equivalent of the Virtual Link Number in a transputer system, and addresses a particular channel in the destination hardware. The optional bytes provide a header delimiter for (probably unnecessary) additional security, and a longitudinal parity checksum which detects multiple-bit errors, and which is easily modified as headers are stripped from the packet.

Unicast	**Multicast**
Header byte for First switch	Header byte for multicast
Header byte for Second switch	(optional) Header Delimiter
Header byte for Third switch	Payload
...	
Channel Identifier	
(optional) Header Delimiter	
Payload	(optional) Longitudinal Parity
	Terminator
(optional) Longitudinal Parity	
Terminator	

Table 1: Packet/cell format

	Bit 0 , Output Port 0	Bit 1, Output Port 1	Bit 2, Output Port 2	Bit 3, Output Port 3	Bit 4, Output Port 4	Bit 5, Output Port 5	Bit 6, Output Port 6	Bit 7, Output Port 7	Bit X, Multicast, don't strip
Header byte = 1	1	0	0	0	0	0	0	0	0
Header byte = 2	0	0	1	1	1	0	0	1	1
Header byte = 3	0	0	1	0	0	0	0	0	0
Header byte = 4	0	0	0	1	0	0	0	0	0
Header byte = 5	0	0	1	0	0	0	0	1	1
Header byte = 6	0	1	0	0	0	0	0	1	1
Header byte = 7	1	0	1	0	0	1	0	0	1
Header byte = 8	0	0	0	0	0	0	0	1	0
Header byte = 9	1	1	1	1	0	0	0	0	1
Header byte = 10	0	0	0	0	1	1	0	0	1
Header byte = 11	1	0	0	0	0	0	0	0	1
Header byte = 12	0	0	0	0	1	0	0	0	0
Header byte = 13	0	0	0	0	0	1	0	0	0
Header byte = 14	1	1	0	0	1	0	0	1	1
Header byte = 15	0	1	0	0	0	0	1	0	1
Header byte = 16	0	0	0	0	0	0	1	0	0
Header byte = 17	0	1	0	0	0	0	0	0	0
Header byte = 18	1	1	1	1	1	1	1	1	1

Table 2: Routing look-up table for priority arbitration on header values

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A look-up table associates each multicast channel with one or more of the output ports. If the look-up table is used both for multicast and unicast, the channel number can be used to provide a priority mechanism. Table 2 shows an example of such a look-up table, with one bit-column per output port of the switch, and one extra bit-column to indicate that this is a multicast packet/cell whose header is not stripped. The various channels are arranged in an arbitrary order, with the highest priority channels at the top.

5. Line coding for the routing switch

A major contributing factor to the feasibility and low cost per port of the SGS STC104 is the use of Data/Strobe (DS) encoding of the signal and clock, so that there is no need in the switch for a PLL clock recovery circuit on each port. While not an essential aspect of the home network the exceptionally simple clock recovery (with an exclusive OR gate) could be a great advantage, as it has been to 1394.

An additional advantage from the use of DS encoding is that it is possible to use a spread-spectrum clock [4] to flatten any spikes resulting from harmonics of the transmit clock frequency. Figure 2 shows the DS signals and recovered clock.

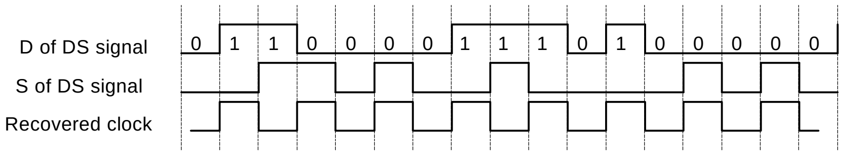

Figure 2: Waveform diagram showing the D and S signals of DS-Links and recovered clock

6. Creating a suitable signal for domestic UTP

A serious problem with IEEE 1355 as it stands is that the cabled options are not DC-balanced, which is necessary to provide transformer coupling for isolation.

A code which is able to convert an unbalanced code into a balanced one is HP's RMI code [3], which apart from having excellent spectral properties, also has the useful property that it preserves transitions. So we code the DS signals with RMI as shown in Figure 3.

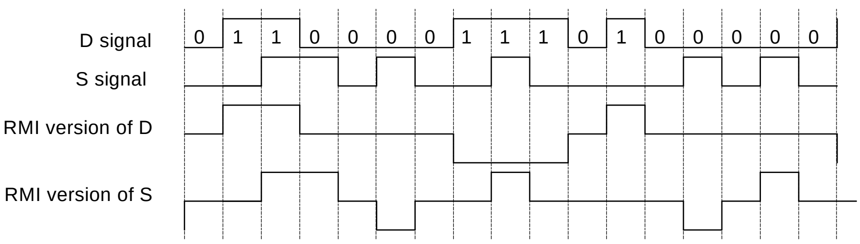

Figure 3: Waveform diagram showing the RMI versions of D and S signals

HP suggest precoding the signal before RMI coding in order to limit the run-length and so ensure that transitions are always between –1 and 0, 0 and –1, +1 and 0, or 0 and +1, and never between –1 and +1 or +1 and –1. So we precode the signal in order to limit run lengths on both D and S. In doing this, we provide a D signal whose binary version (before RMI coding) is also DC-balanced and is suitable for transmission down plastic optical fibre (POF).

7. Reducing power

Power consumption is of increasing importance and the growing "Green" consciousness is particularly relevant to wasting power. Use of DS and RMI make it possible to take the signals quiescent and stop the clock when there is nothing to transmit. Figure 4 shows an example of the signals going to standby, where the running digital sum of both D and S is zero, and the state of both D and S is zero.

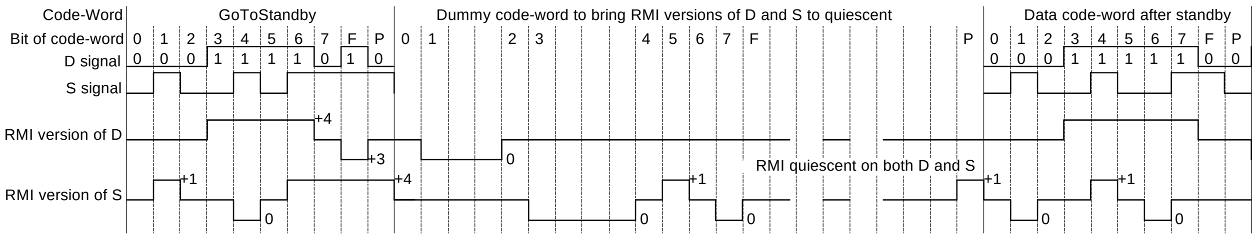

Figure 4: Waveform diagram showing the RMI signals going to Standby

When there is something new to transmit, the signals can start up almost immediately.

8. Minimising cable traffic to reduce power further

If the network was logically a bus, as it would be with Ethernet or 1394 connected via repeaters, all the traffic in the network needs to visit every node, so there would be no advantage in being able to reduce power in the absence of traffic: if there is any traffic anywhere in the network, the whole network needs to be powered.

IEEE 1355 is particularly efficient for unicast traffic, in only using the necessary connections between two nodes. For multicast traffic, however, 1355 as currently implemented needs to send separate messages from the source node to each multicast destination.

The routing protocol described in Tables 1 and 2, with both unicast and multicast, ensures that each message has only one source, and only travels once on each connection. Figure 5 shows an example of a possible topology of the network, with a unicast message going from A to DAA, and a multicast message going from CA to B, CB, DB, EBB, and FA,

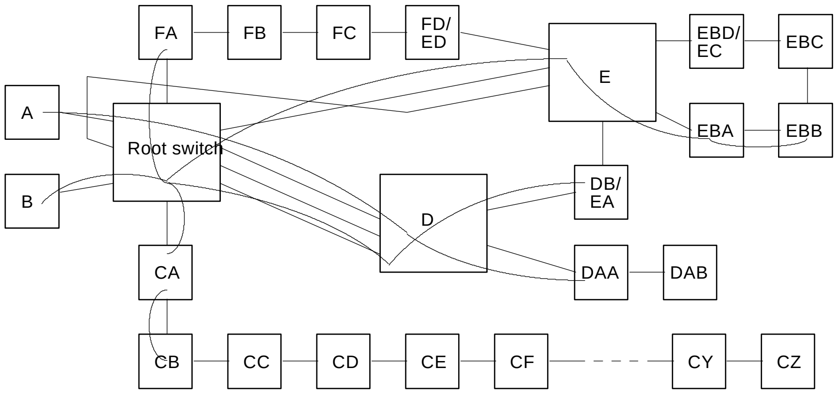

Figure 5: Set of possible connections in a home network

The combination of a routing protocol which only uses the necessary wires so that most of the wires in the network can be without traffic, and a line code which lets wires without traffic go quiescent to reduce power and resulting RFI emissions, gives an exceptionally environmentally conscious solution to the home network. This is further enhanced by the use of a spread-spectrum clock to reduce the peaks of RFI emissions at harmonics of the link clock frequency.

9. Proposed port based on DS and RMI

A disadvantage of the DS signalling of IEEE 1355 and 1394 is that it appears to need two pairs for each direction. 1394 only uses half duplex, but full duplex has significant advantages. Telephone circuits, however, use "hybrid" transformers to carry both directions on the same wires, and we use this technique to provide full-duplex. Hybrid transformers also provide a phantom circuit which can be used to distribute power, or to be used for an integrated lower speed communication system such as CEBus, LON, WattCAN [5] or even ISDN. An overall block diagram of a port showing the coder, decoder, hybrid transformers and phantom circuit, is shown in Figure 6.

It is evident from Figure 6 that the receivers rectify the incoming signal, so that the circuit is insensitive to the polarity of connection of the twisted pairs. A small amount of additional circuitry can also make the circuit insensitive to whether the D and S signals are swapped, providing excellent tolerance to wiring by the untrained users inevitable in the home environment.

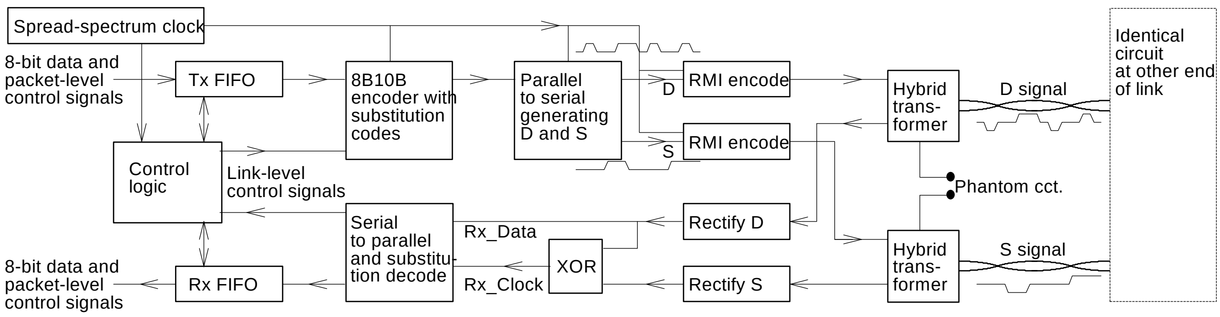

Figure 6: Overall block diagram of transceiver for code, using hybrid transformers

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10. Conclusions

What we have presented is an approach to home networks which:

- fully integrates the various aspects of the network including not only video but also power distribution and control bus
- puts the very high data rates where they can be handled easily — inside silicon — rather than putting them on every wire in the house
- uses a simple routing protocol which offers low-cost switches capable of handling both unicast and multicast messages
- preserves the significant advantage to both 1394 and 1355 of DS signalling
- uses an excellent transmission code (RMI)
- is secure, green, and user tolerant

11. Acknowledgements

We are grateful to Alistair Coles of HP for inventing and publishing the RMI code, to Colin Whitby-Strevens of SGS-THOMSON who made us aware of the RMI code and has otherwise greatly encouraged this work, and to Neil Davies of Bristol University, who encouraged our belief that "green" networks were worth-while.

12. References

[1] IEEE, *IEEE P1355(1995) Standard for Heterogeneous Interconnect (HIC)* available from IEEE Standards.

[2] National Semiconductor and SGS-THOMSON, *IHDEN-VESAHN: In-Home Digital Entertainment Network*, proposal to VESA, 12 Feb. 1996

[3] A N Coles, *New Pseudoternary line code for high-speed twisted pair data links*, Electronics Letters, 9 November 1995, pp 1976-1977

[4] Spread spectrum clocks are described in data sheets such as that for the IMISM530 from International Microcircuits Inc., 525 Los Cloches St, Milpitas CA 95035 USA

[5] WattCAN is a derivative made by D2D (Design To Distribution Limited, Kidsgrove, UK) of the Control Area Network (CAN) standard.

[6] The ATM Forum's Residential BroadBand (RBB) activity is the main focus for the ATM Forum on Home Networks

[7] IEEE, *IEEE 1394(1995) Standard for Serial Bus* available from IEEE Standards.

[8] A data sheet for the ICR C416 Routing switch is available from IC Routing Ltd, Newton Building, Burton Street, Nottingham, UK

[9] A data sheet for the STC104 is available from SGS-THOMSON Micrelectronics, from www.st.com/stonline

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