Personal Computer Based

Home Automation System

By

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(abstract)

The systems engineering process is applied in the development of the preliminary design of a home automation communication protocol. The objective of the communication protocol is to provide a means for a personal computer to communicate with adapted appliances in the home.

A needs analysis is used to ascertain that a need exist for a home automation system. Numerous design alternatives are suggested and evaluated to determine the best possible protocol design. Coaxial cable, fiber optics wire, infrared, and the home power line are each evaluated to determine which would best serve as the communication medium for the communication protocol. A personal computer and a dedicated computer are compared to determine which computer configuration will be used to control the communication protocol. The final design choice which is considered is the LAN protocol type. CSMA/CD and Token Bus are evaluated to determine which protocol type will best support the home automation system.

The results of the system engineering process is a preliminary design for a home communication protocol that will use the home power line, a personal computer, and a CSMA/CD LAN protocol to provide a home communication protocol.

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Chapter 1: Introduction

Paper Goal

The goal of this paper is to apply the systems engineering process to the development of a communication protocol that will allow the home to be automated. The communication protocol will allow for communication between a central computer and consumer electronic devices in the home. The protocol is developed such that manufacturers of consumer electronic devices will be capable of designing their products such that they are compatible with the communication protocol. In this way, eventually a large portion of the appliances in the home will be automated by the central computer.

The communication protocol is developed by following the Systems Engineering Process described in Blanchard's (1) book Systems Engineering And Analysis. The first four chapter of the book represent the conceptual design of the communication protocol. The report begins with needs analysis where the result of a consumer survey and home automation demonstration are used to demonstrate a real need for a computer based home automation system. Chapter three presents the feasibility study where numerous technical approaches to the development of the communication protocol are examined. Chapter four is used to develop the system operational requirements which are used throughout the rest of the paper to guide the development of the communication protocol. Chapter five is the preliminary system analysis where the needs analysis and system operational requirements are used to evaluate the technical approaches that were presented in the feasibility study. The results of the preliminary system analysis is the choice of the technical approaches that will be developed to produce the communication protocol preliminary design.

The next two chapters present the technical analysis which will lead to the preliminary design of the communication protocol. Chapter five is the system functional analysis. The system functional analysis presents the system operational requirements in a functional form by representing them in functional flow diagrams. Chapter six summarizes the synthesis and definition where the final preliminary design for the communication protocol is developed.

The reader should be aware that the data presented in the needs analysis as a survey and demonstration was actually derived by examining numerous sources such as the Wall Street Journal, Byte Magazine, Popular Science Magazine, and the results of the 1990 census. There was no actual survey or demonstration conducted. The survey, demonstration, and their results are presented as factual in order to demonstrate how such information would be used if the resources were available to carry them out.

Chapter 2: Definition Of Need

Conceptual Design Introduction

The conceptual design phase is the first step in the systems engineering process. (1,p.25) The conceptual design phase employs a structured methodology in the determination of a set of system specifications for a system that will satisfy a defined need. The conceptual design phase starts with the definition of the need for a system or product. (1,p.35) Once a need has been clearly defined, a feasibility study is conducted to determine which technologies if any can possibly be used to develop a system that will meet the defined need.

Both the results of the definition of need and the feasibility study are used as input into the process of developing the set of system operational requirements. The operational requirements are the set of technical parameters that will be used to drive the system design.

The system operational requirements can be used to produce an evaluation criteria to determine which of the design alternatives originally identified as part of the feasibility study is bested suited to fulfil the need. The process of evaluating the various design alternatives is referred to as the Preliminary Systems Analysis. The result of the Preliminary System Analysis will be a recommendation as to which design alternative is most appropriate.

The final stage of the Conceptual deign phase is to use the results of the Operational Requirements and the Preliminary System Analysis to produce the System Specifications.

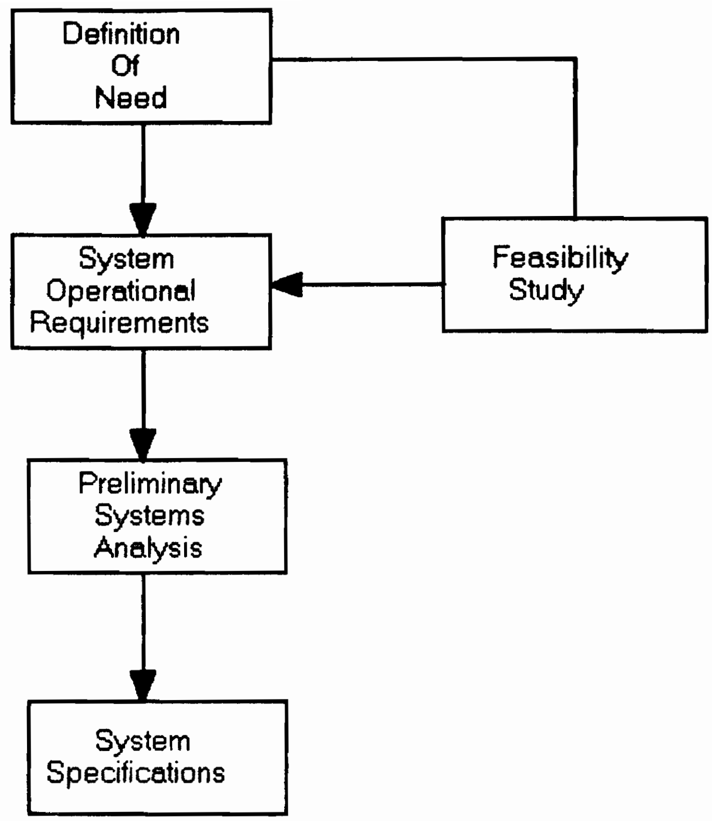


Figure. 2.1 Conceptual Design Flow

Needs Analysis

Introduction

The needs analysis provides a medium where a designer identifies a need for a product or system. (1,p.35) The identified need should be based on a perceived lack of capability. The defined need is the starting point in the systems engineering process.

A designer should avoid the temptation of developing a system without first determining what need the system will be satisfying. A system that is developed for a reason other than satisfying a specific need will likely develop cobwebs sitting on a shelf. Often times when a design effort begins with no needs analysis, a design team will lose sight of their original goals halfway through a project. A product designed in this way will not be the product originally envisioned, and the design effort will have cost more than was required.

When a design effort begins with a clearly defined need the systems engineering process can be utilized to develop a system that will satisfy that need. Blanchard (1,p.36) recommends the following subjects be addressed in the needs analysis:

> 1. The nature of the existing deficiency be well defined (inadequate performance characteristics, inadequate system support capability, excessive ownership cost, and so on).
> 2. The date by which the new system must be installed and operational be established.

3. The magnitude of the resources for investing in the new system capability be identified.

4. The relative priority of the new system capability be established.

If the need is determined to be grave enough, the response to the above queries should provide the stimulus for the definition of the requirements needed to define a system capable of removing the need.

Analysis

In order to determine if a need exist for a home automation system the following steps were taken. First a survey of over 2,000 people was conducted to determine if there was a market for a home automation system, and if their was a need how great of one. Second, thirty-five people who had already indicated an interest in a home automation system were paid to participate in a short home automation demonstration. The purpose of the demonstration was to answer questions about specifically what consumers wanted to see in a home automation system. The demonstration participants were exposed to various components that possibly would be part of a home automation system. Careful notes were taken to determine what features the consumers had a positive response to and which consumers had a less than positive response to.

Home Automation Survey Results

The survey was broken into three major segments. The goal of the first segment of the survey was to gain information about the person taking the survey. This goal of the second part of the survey was to ascertain if the consumer was interested in a home automation system, and if he was how much would he be willing to pay for a home automation system. The goal of the third part of the survey was to determine what characteristics those consumers interested in a home automation system would like to see in a home automation system. The following paragraphs are a summary of the results of the home automation survey.

Figure 2.2 illustrates the results found when the survey participants were asked "Are you interested in a home automation system?" As shown in Figure 2.1 eighty-five percent (1700 people) of the respondents answered either yes or maybe when asked if they would be interested in a home automation system. Out of the eighty-five percent responding favorably to a home automation system thirty-five percent said they would definitely be interested in a home automation system while fifty percent said they might be interested in a home automation system. Only fifteen percent (300 people) told survey takers that they would not be interested in a home automation system.

When members of households where both the husband and wife work were asked if they would be interested in a home automation system the number of respondents who said yes or maybe was still eight-five percent, but in the dual income case the mix between yes and maybe was fifty percent yes and thirty-five percent no. Figure 2.3 represents the responses of the members of households with dual incomes.

The results of the survey indicate a real interest among consumers for a home automation system. If the results of the survey can be applied to the American public as a whole then there would be a market of over thirty-two million households interested in home automation. If the number of persons who responded maybe are included in the count then there are over seventy-eight million households who are interested in purchasing a home automation system.

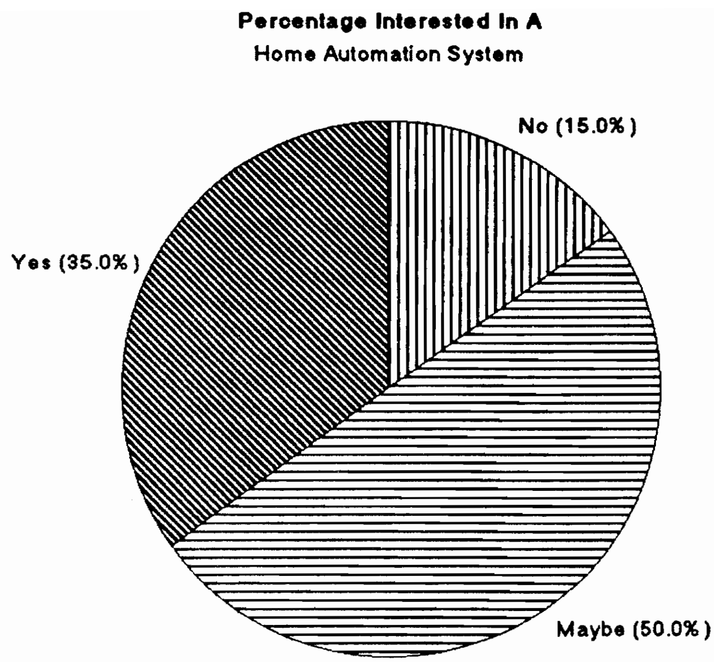


Figure 2.2 Percentage Of Americans Interested In Home Automation

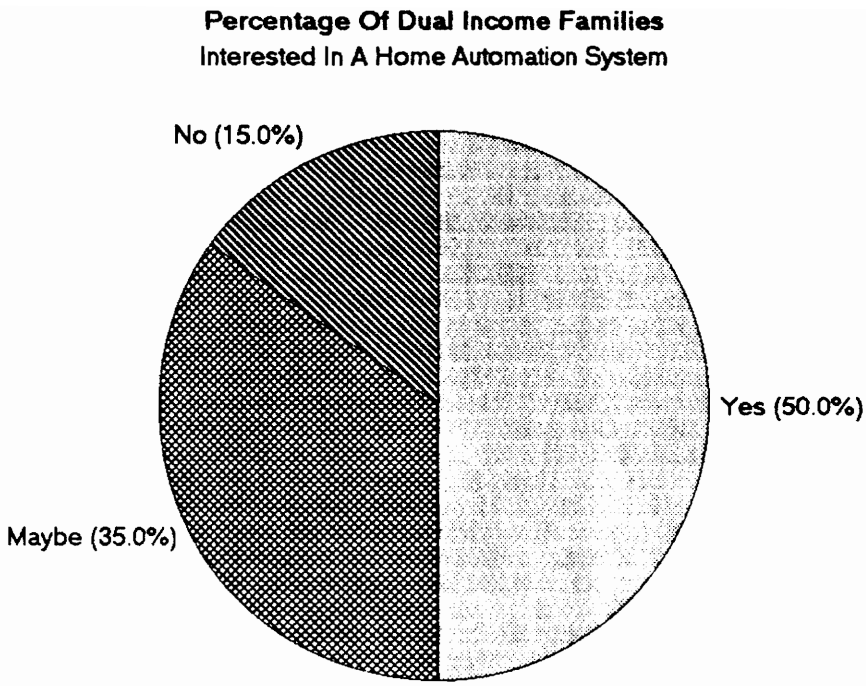


Figure 2.3 % Of Dual Income Families Interested In A Home Automation System

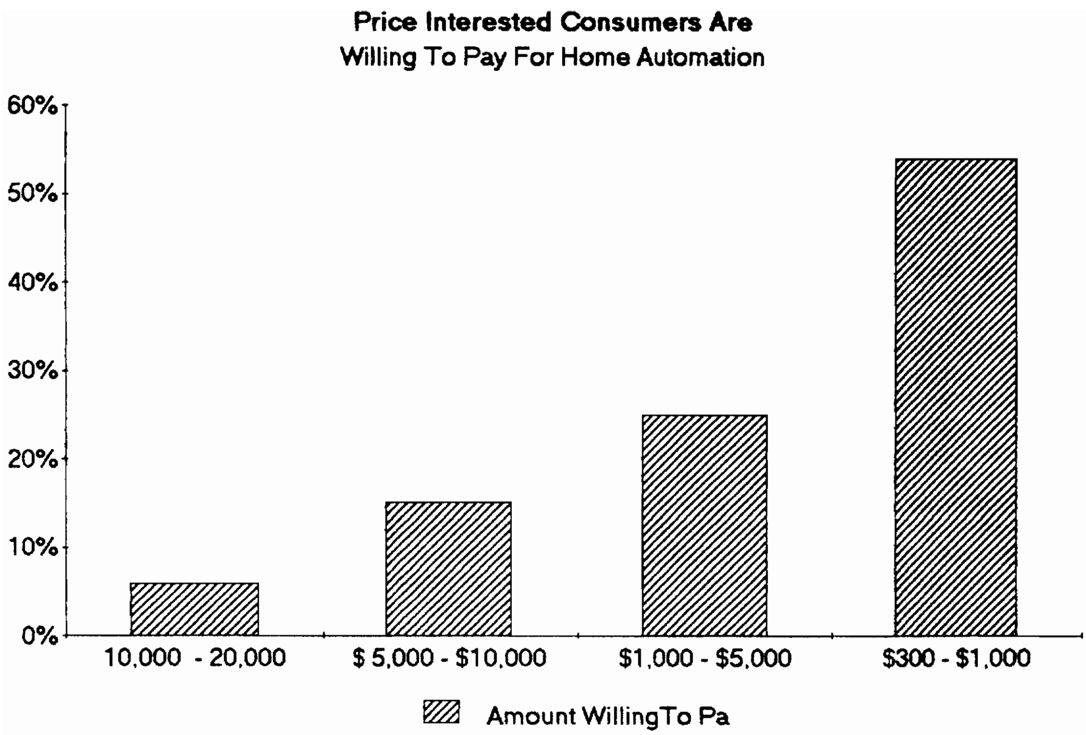


Figure 2.4 Desired Price For Home Automation System

Figure 2.4 illustrates how the consumers responded when asked, "How much would you be willing to pay for a home automation system?" . Figure 2.4 shows that the majority of respondents would like to pay between $300 and $1,000 for a home automation system. While there were a small number who were willing to pay in the $10,000 to $20,000 range (7%), over 54% desired to pay less than $1,000. Figure 2.5 shows that even the majority of the two income families interested in a home automation system desired to pay less than $1,000.

The survey also indicated that forty percent of those who answered "maybe" when asked if they were interested in a home automation system would change their answer to "yes" if the automation system could be purchased for less than $1,000.

Each of the consumers who reacted positively to the concept of home automation was asked which devices they would like to see automated. The following series of bar charts indicate the results of these questions and indicates which devices consumer would like to see automated.

The surveyed indicated that there is fairly consistent set of devices around the home that consumers would like to have automated. The home automation system should be capable of allowing for the automation of the following devices: TV, thermostat, answering machine, VCR, stereo, conventional oven, microwave oven, smoke detector, home security, home intercom, coffee maker, and lighting.

Consumers also were asked how many appliances they presently have in their home, and whether they believe the number of appliances found in their home will continue to increase. Eighty-seven percent of the respondents indicated that they expected the number of appliances and consumer electronic devices in their home to increase substantially over the next ten years.

Those who indicated that they expected the number and type of appliances in the home to increase, were asked how important it would be to them that their home automation system was flexible enough to expand

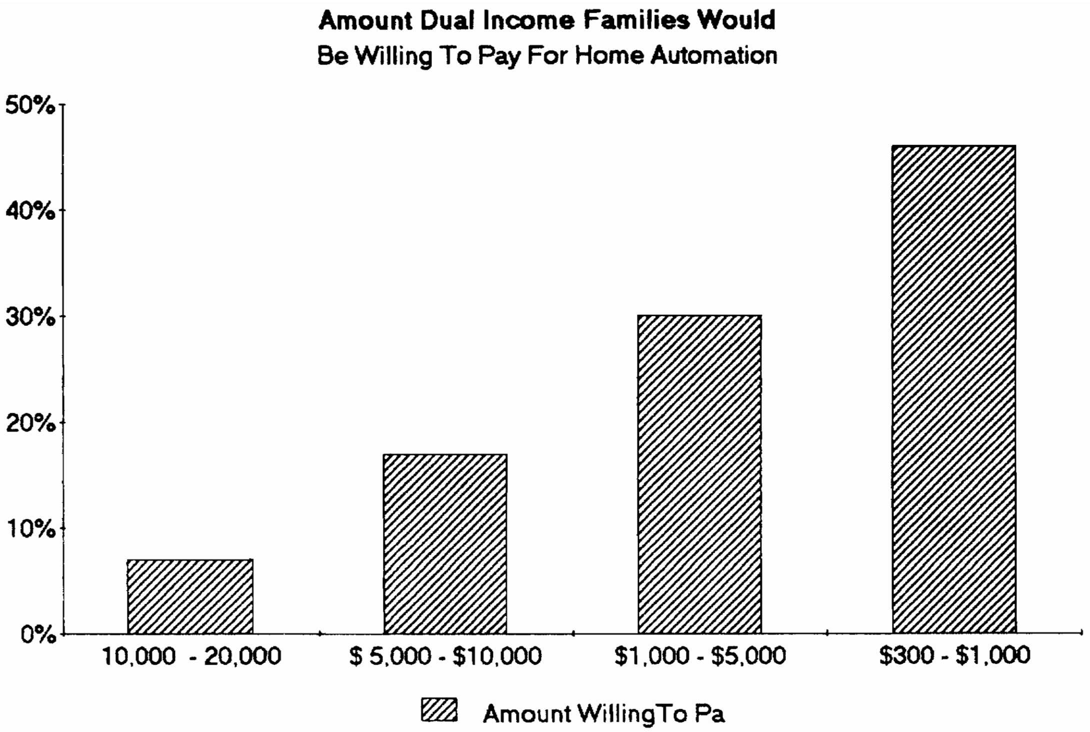


Figure 2.5 Price Dual Income Families Would Like To Pay For Home Automation

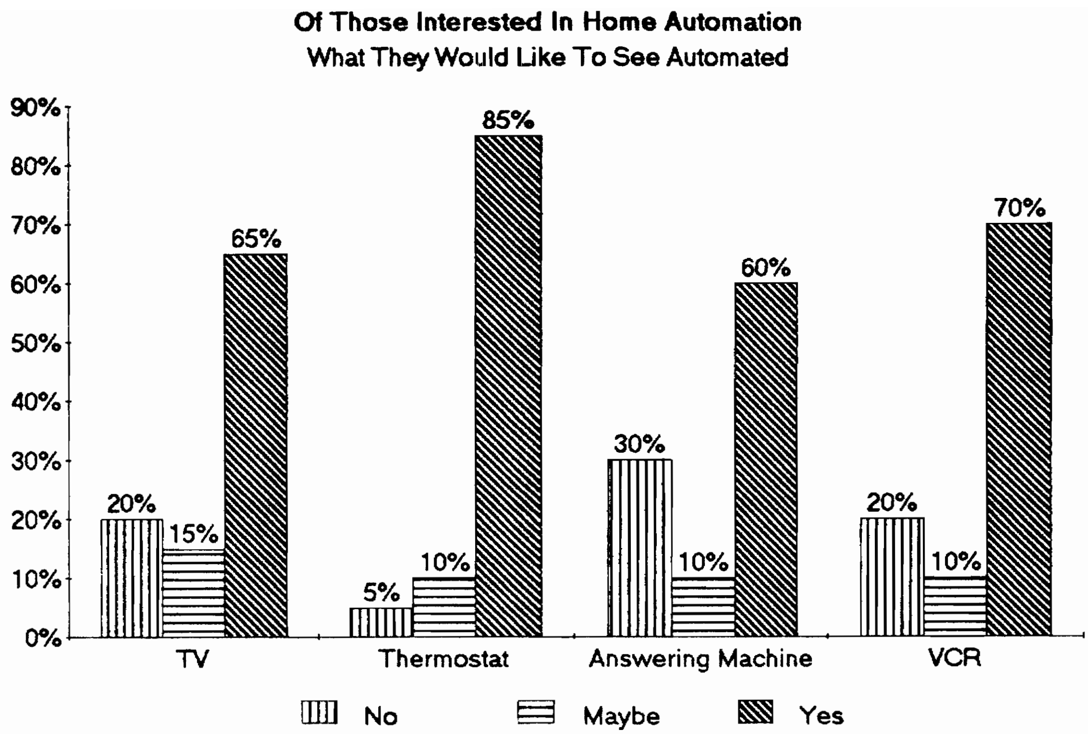


Figure 2.6 Which Appliances Consumers Would Like To See Automated

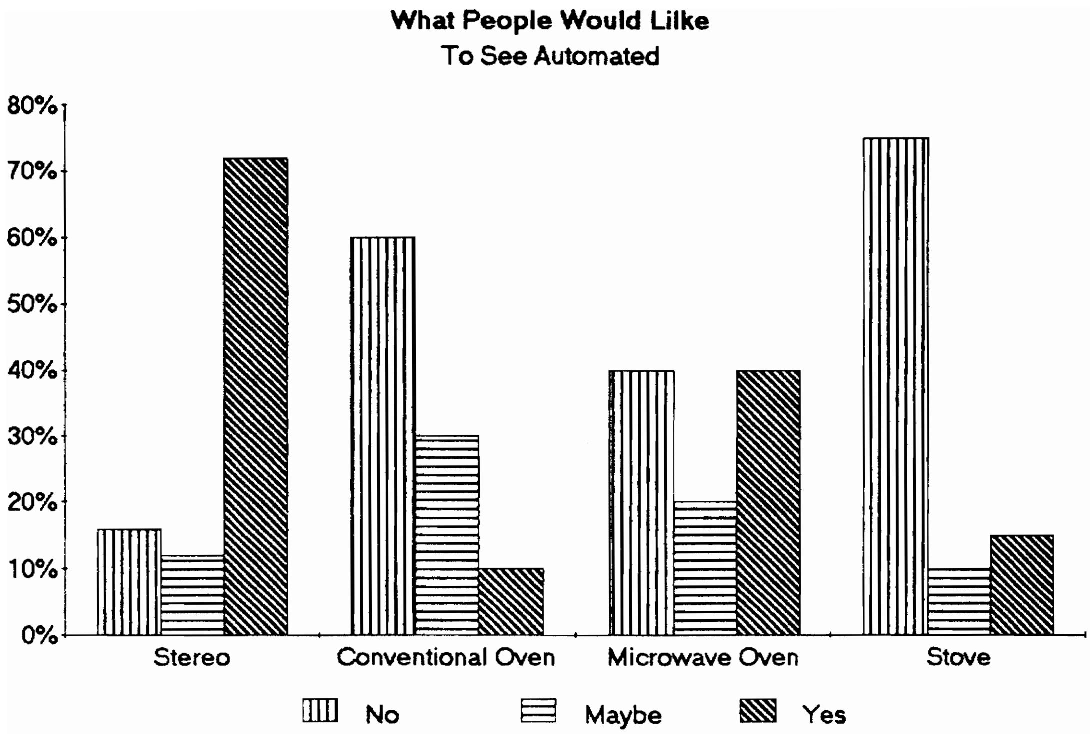


Figure 2.7 Which Appliances Consumers Would Like To See Automated

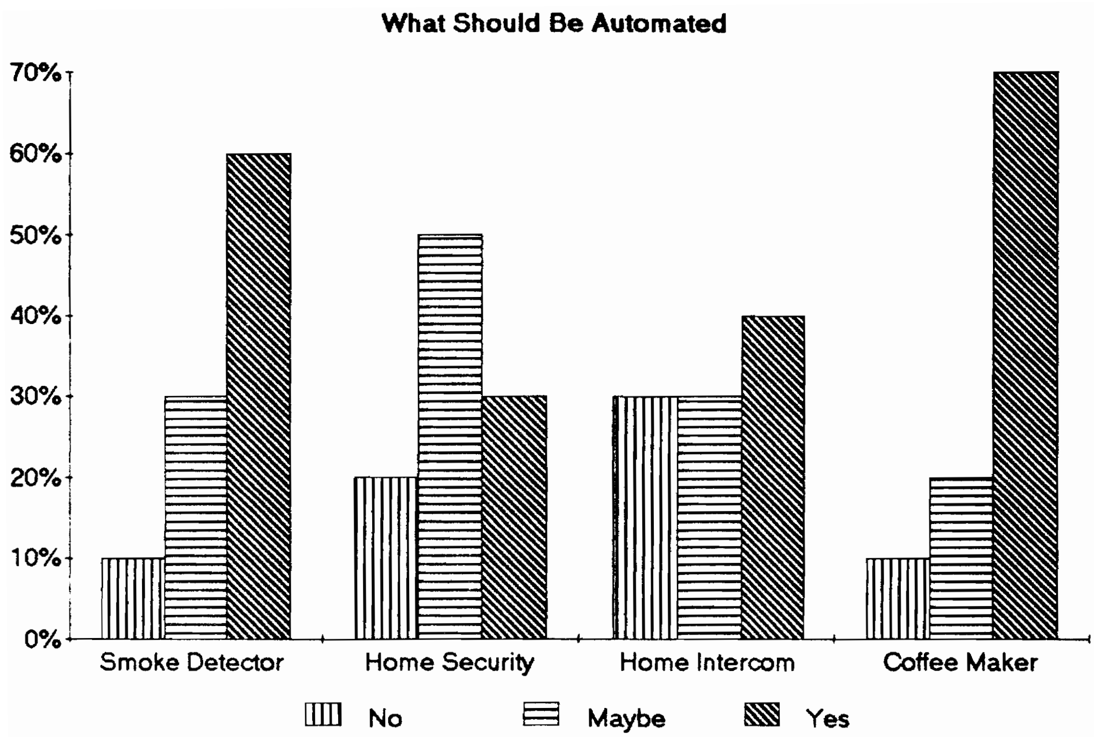


Figure 2.8 Which Appliances Consumers Would Like To See Automated

to support the new devices. Consumers overwhelmingly indicated that a systems ability to expand to handle an increase in the number of automated appliances would be very important to them when considering whether to buy a home automation system.

Consumers were asked how much of an increase in the cost of an appliance they would tolerate in order to make the appliance compatible with a home automation system. The largest percentage of the consumers gave indicated that anything under $50.00 would be a reasonable addition to the price of an appliance in order to make it compatible with a home automation system.

Each consumer was also questioned to determine if they owned a personal computer. Figure 2.9 indicates the number of those responding that also own their own personal computer. Those surveyed who showed interest in home automation but indicated that they did not have a personal computer were asked if they would be willing to purchase a personal computer if they knew that it could be used as not only for normal home computing purposes but also as part of a home automation system. Figure 2.10 shows the percentage of people who would consider purchasing a home computer if it could also as part of a home automation.

Home Automation Demonstration Results

A demonstration of various home automation capabilities was given to a group of thirty-five consumers who had shown an interest in a home automation system. The results of this survey were examined to help determine what features in a home automation system would be important to make a consumer purchase such a system. The following paragraphs discuss the important observations made during the home automation demonstration.

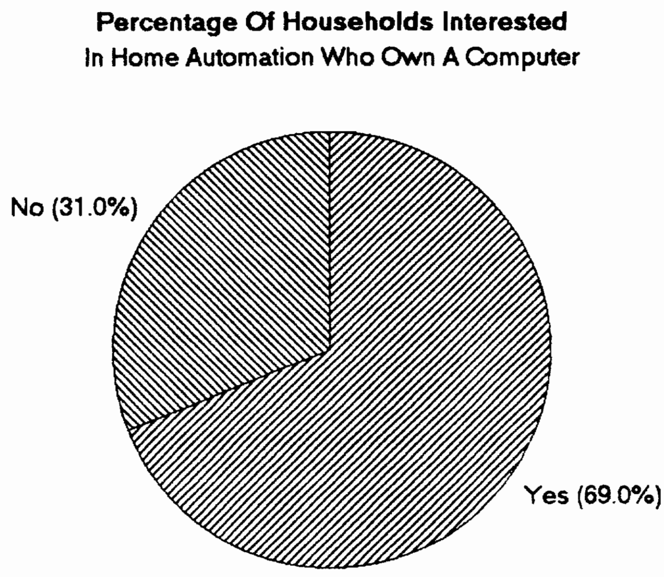


Figure 2.9 Percentage Of Those Interested In Home Automation Who Own A Personal Computer

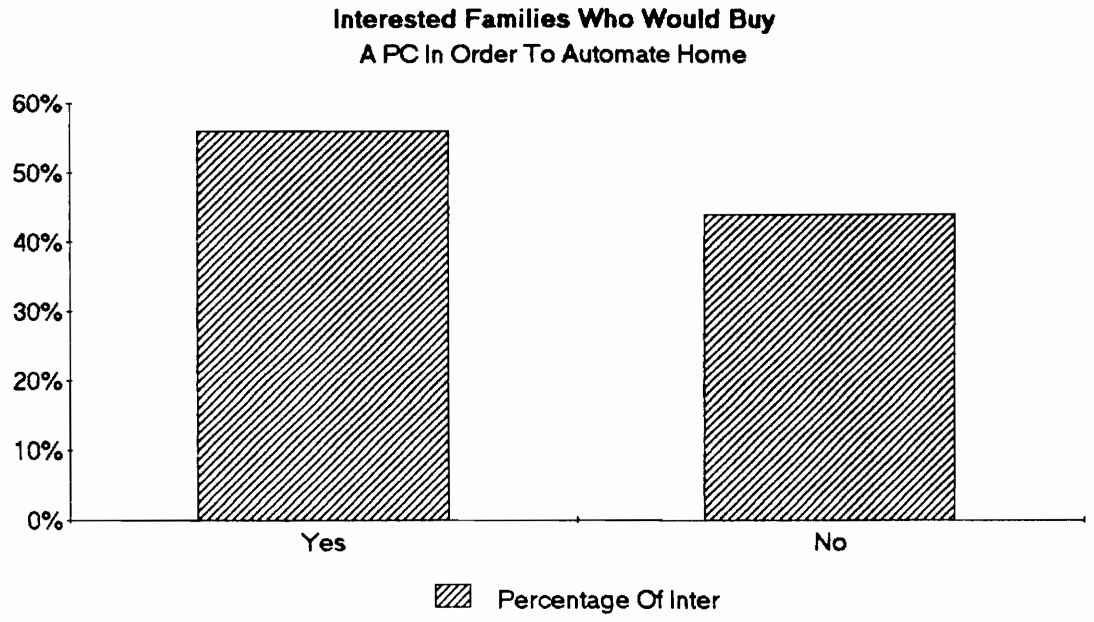


Figure 2.10 Percentage Of Those Interested In Home Automation Who Would Purchase A Computer

System Reaction Time

Each consumer participating in the demonstration was asked to turn various appliances on and off using a hand held remote control. The response time of the appliance to the remote control was adjusted to determine how the response time of the system affected the consumer's view of the system. It was found that a quick response to a command given to the automation system was very important. When it took more than five seconds for the appliance to respond there were two negative affects on the consumer. First the consumer indicated that the delay in response of the appliance negatively impacted there trust in the home automation system. The second problem with the slow response time is that the consumer would become inpatient and press the on off button again. The result of this is that immediately after turning on in response to the first time the "on" button was pushed the appliance would immediately turn off in response to the second time the button was pressed.

In order to avoid the problems associated with a slow response time it was determined by trial and error that the system should have a response time of less than one half of a second (.5 seconds). When an appliance responded in less than one half of a second the consumer involved in the demonstration indicated that they thought the system had responded instantaneously.

The reliability of the system was also very important to the consumers. Consumers showed a great deal of disappointment when a command was issued to a particular device and there was no response from the device or the wrong device responded. Participants in the demonstration were asked to turn a light on with a remote control. In each case, when the consumer pressed the proper button to turn the light on either the light would not respond or a television in the room would turn on. When interviewed about the home automation system demonstration the consumers indicated that having confidence that the automation system would respond correctly to commands was very important.

Identification Of Need

Based on the results of the home automation survey and consumer demonstration it has been shown that there is a clear need among American consumers for a system that will allow for the automation of appliances in the home. The survey also indicated that the average American consumer will be unlikely to pay more than $1,000 for a system that will allow his home to be automated.

The survey indicates that the home automation must have the capacity to automate the following devices: TV, thermostat, answering machine, VCR, stereo, conventional oven, microwave oven, smoke detector, home security, home intercom, coffee maker, and lighting. The survey also indicated that consumers will be more likely to purchase a home automation system if they believe that the system will be flexible enough to support their home automation needs as the type and number of appliances that can be automated increase.

Proposed Solution

The computer based home automation survey and consumer demonstration indicated that there is a large demand for a home automation system. The survey showed that a large portion of American consumers are interested in a system that will allow a computer to automate various appliances and consumer electronic devices around the home. In order to automate devices around the home some type of computer configuration will be required to provide synchronization and control of the automated devices. Irregardless of what type of computer is used a method of allowing the computer to communicate with the devices that are to be automated must be provided.

In order for a computer to communicate with the devices that are to be automated a bus must be provided that will allow data and control signals to pass between the controlling computer and the devices. Since numerous devices will be automated, and the potential exist that more than one device will need the bus at the same time, a protocol must be developed that will allow numerous devices to share the communication bus. The communication protocol must be well defined in order to allow the manufactures of consumer electronics to build their products such that they are compatible with the protocol.

The remainder of this paper will deal with the development of a protocol that will allow a controlling computer to communicate with devices in the home. The goal of this paper will not be to develop the designs of the appliances that will interact with the communication bus. Although, the communication protocol will define the guidelines that will be followed by any appliance that will be automated by the system.

Chapter 3: Feasibility Study

The feasibility study is an important part of the early stages of the systems engineering process. After the need for a system has already been established, the feasibility study is used to determine what system configurations might be used to satisfy the need. The feasibility study provides a mechanism for designers to examine the technology available and determine what system configurations and technical approaches could be used to produced the desired system.

The technical approaches identified in the feasibility study are later evaluated to determine which design alternative is most appropriate for further investigation. This evaluation is carried out by comparing each of the technical approaches to the set of operational requirements.

The following paragraphs will examine the three major design choices that must be made in the design of the home automation communication bus. For each of the three major design choices a list of alternatives solutions will be listed and described. The three design choices are: what type of control computer configuration is best, what type of communication medium should be used, and what type of local area network (LAN) protocol should be used.

Control Computer Configuration

The issues associated with the controlling computer are: what type of computer will be used and how will that computer be configured relative to the rest of the home automation system. Two different alternatives have been identified for both the question of what type of controlling computer should be used and what type of configuration should be used. Table 3.1 is a matrix showing the four design alternatives. Each of the design alternatives are described below.

Table 3.1 Possible Computer Configurations

	Distributed Control	Centralized Control
Dedicated Controlling Computer	Distributed Control With Dedicated Controlling Computer	Centralized Control With Dedicated Controlling Computer
PC Based Controlling Computer	Distributed Control With PC Based Controlling Computer	Centralized Control With PC Based Controlling Computer

Dedicated Computer

The first alternative for the type of computer that will be used is to develop a dedicated special purpose computer for the sole purpose of controlling the home automation system. The stand alone computer would require a CPU in order to provide processing capability, a display to allow a consumer to determine the status of the computer, a keyboard to allow a consumer to control the computer, firmware and/or software to direct the computer, and possibly a disk drive to allow the computer to be loaded with updates to its software.

The technology exist today to allow development of a special purpose computer. The same low price technology that is constantly driving the cost of personal computers down is the technology that would be used to build a special purpose home automation computer.

A computer designed specifically to control a home automation system would have two major advantages. First since the computer was designed to only control a home automation system it would be fast compared to a similarly outfitted general purpose computer. Second since the computer is a special purpose device, much of the system control could be implemented in hardware rather than software.

General Purpose Personal Computer

This design alternative calls for the personal computer already found in many American homes to be used to control the home automation system. Figure 3.1 shows that the number of homes in the United States with computers in them has constantly increased. Today over 30,000,000 million homes have computers in them. And almost seventy percent of the 2,000 people who showed interest in a home automation system already own a personal computer.

The biggest advantage of this design alternative is that a large amount of computer power is made available to the home automation system at a minimal price. The computers found in many American homes today are not only very powerful but have advanced human machine interfaces; such as high resolution graphics, printers, phone modems and pointing devices. Figure 3.1 illustrates how the power of home computers found in the American homes have continued to increase in power.

In order to use a personal computer to control a home automation system, software would need to be developed to allow the computer to control the system, and hardware would have to be produced that would allow the computer to interact with whatever communication medium is chosen.

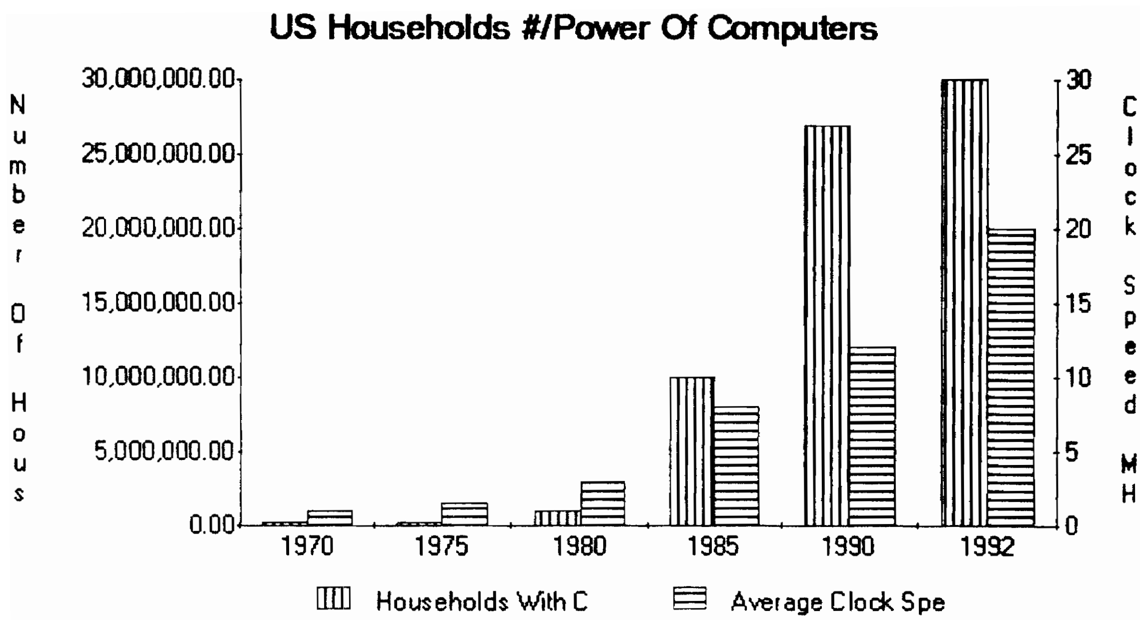


Figure 3.1 The Number And Power OF Computer In American Homes

Distributed Control

Distributed control would require each of the devices connected to the home automation system to have their own built in processing capability. Thus each appliance attached to the home automation system would be required to have its own built in microprocessor. Microprocessor of the type that would be required in each automated appliance (Intel 8085 for example, see Appendix A) are available for less than five dollars.

The advantage of a distributed control system is that the responsibility of the second by second controlling of an appliance would fall under the control of the appliance's built in microprocessor. The controlling central computer would only be required to send an individual command which would cause the microprocessor inside the appliance to execute firmware that would be produced by the manufacturer of the appliance. With this type of system the controlling computer does not have to understand how the automated appliance works, the controlling computer only need know what commands it needs to send to the appliance and when. Since the controlling computer is removed from an intimate relation with the workings of the automated appliance this lessens the likelihood that there would be limitations on the complexity of the actions taken by automated appliances.

Centralized Control

Centralized control would rely on the central computer sending all the signals necessary to cause each automated device to complete its assigned task. This type arrangement could possibly reduce cost added to an appliance in order to automate it.

Communication Medium

As discussed in the definition of need, in order for the appliances in the home to be automated some of mechanism must be provided to allow each automated device to communicate with the central computer and other automated devices. This communication medium must provide a means for all devices that are to be automated and the controlling computer to be connected by some sort of bus that will allow communication at a high enough rate to allow the required system communications to take place.

There are four communication mediums that will be considered are: coaxial cable, multiple infrared links, fiber optics, and the existing home power bus. Each of these design alternatives are discussed below.

Coaxial Bus

A coaxial based system would require that coaxial cable be placed throughout home. Coaxial cable will likely be able to support all of the bandwidth requirements of the home automation system. Coaxial cable is often used to support other types of computer LAN's. Coaxial cable is relatively cheap and very reliable.

Infrared Link

A infrared based system would rely on the same sort of technology that is used in a television remote control. The system would require that infrared receive and transmit repeaters be placed throughout the home to insure that the infrared signal was relayed to every room. Each device that was to be automated would be required to have an infrared receiver and transmitter. Systems similar to the one just describe are already available for the office environment.

Optical Fiber

A optical fiber system would require that optical fiber cable be installed throughout the home. The technology required to provide an optical fiber bus for the home exist today, although it is relatively expensive. The bandwidth capabilities of an optical fiber is huge and signals carried on an optical fiber link are not affected by electromagnetic interference.

Home Power Bus

This method would rely on the already existing copper cable in the walls of every home that are used to distribute electrical power to also provide connectivity between devices attached to the home automation system. Presently there are numerous systems that have been developed to transmit information over the home power line. This system has a cost advantage in that the communication medium already exist in the home and thus would not add to the cost of the system.

Communication Control

Once a communication medium has been established in the home that connects the multitude of devices that will be automated a method has to be developed that will allow all the automated devices to reliably share the communication medium. The two types of LAN protocols that would most likely be suitable for the home automation system are the Token Bus and the Carrier-Sense Multiple Access With Collision Detect (CSMA/CD). Token Bus and CSMA/CD are both very popular protocol types that offer a wide range of communication control capabilities.

Token Bus is a distributed system that controls access to the communication bus by passing a token between devices. When a device has possession of the token it is in control of the LAN. Each device can only keep the token for a set period of time until it must give up the token to the next device on the bus. After the token has circulated to all of the devices on the LAN it starts back to the first device.

CSMA/CD allows for access to the LAN to be controlled on a first come first serve basis. When a device wants to transmit data on the LAN it checks to see if the LAN is busy. If the LAN is open then the device is free to transmits. If the LAN is busy then the device waits for it to open up and then follows algorithm to determine how long after the LAN opens up it must wait to transmit. If two devices transmit at the same time then each if the devices detect the collision of their signals and terminates their transmission. After a collision, a device must follow another algorithm to determine when it can attempt transmission again.

Chapter 4: System Operational Requirements

Introduction

Once a deficiency has been described in the form of the definition of need, the attributes of the system that will relieve that need must be determined. That list of attributes comes in the form of the system operational requirements. (1,p.36) The system operational requirements is a projection of how the system will be used, the environment that it will be used in, the extent of its deployment, and the extent of the required support. Blanchard (1,p.37) in his book Systems Engineering And Analysis recommends that the following subjects be addressed in the generation of the system operational requirements:

1. Mission definition - identification of the prime operating mission of the system along with alternative secondary mission. What is the system to accomplish? How will the system accomplish its objectives?

2. Performance and physical parameters - definition of the operating characteristics of functions of the system (e.g. , size weight, speed, accuracy, output rate, capacity) . What are the critical system performance parameters.

3. Use requirements - anticipated use of the system and its elements (e.g., hours of operation per day, on off sequences, operational cycles per month). How is the system to be used in the field?

4. Operational deployment or distribution - identification of the quantity of equipment, personnel, facilities, and so on, and the expected geographical location to include transportation and mobility requirements. How much equipment and associated software is distributed, and where it is to be located?

5. Operational life cycle - anticipated time the system will be in operational use.

6. Effectiveness Factors - system requirements specified as figures-of-merit for cost effectiveness, operational availability, dependability, logistic support effectiveness, mean time between maintenance, failure rate, maintenance downtime, facility use, operator skill levels, and tasks, personnel efficiency and so on.

7. Environment - definition of the environment in which the system is expected to operate (e.g. temperature, humidity, arctics, tropics, mountainous flat terrain, airborne, ground, shipboard).

The subjects listed above provide a guideline to be used in the development of system operational requirements. The following paragraphs develop a set of operational requirements for the home automation system.

Mission Definition

The prime mission is to provide a system that will allow for the automation of the appliances and consumer electronics in the home. The ability of a home to be automated will be provided by establishing a communication network in the home that will allow any properly adapted appliance to talk to other such devices and a central computer which will control the system.

Cost

Based on the home automation survey it is important that the cost of the automation system to the consumer be less than $1,000. If the cost should rise above $1,000 then the number of consumers who will consider purchasing a home automation system will decrease.

The total cost of the system will be made up of the cost of each of the components. The major components of the system will be: the controlling computer, the software for the controlling computer, the communication medium, the interface hardware between the controlling computer and the communication medium, and the distributed cost associated with the development of the various components.

Also the survey indicated that the cost that will be added to an appliance in order to make it compatible with the home automation system must be less than fifty dollars. This cost will include both the hardware that will allow the appliance to respond to information taken off of the communication medium, and any hardware that will allow it to interface with the communication medium.

The following chart summarizes the operational requirements associated with cost that were derived from the results of the home automation survey.

Table 4.1 Home Automation System Cost Requirements

	Cost	Components
Home Automation System	Less Than $1,000	- Controlling Computer - Interface Hardware - Software - Communication Medium - Development Cost
Appliance Compatibility	Less Than $35	- Applinace Control Hardware - Interface Hardware

Data Rate

In order to support the automation of multiple devices the communication medium and all devices attached to it will be required to support a data rate high enough to match the needs of all the devices. The derivation of what data rate will be required is based on two factors. First what data rate will be required in order to successfully provide for the automation of all the devices listed in the definition of need. Second what data rate above that required to automate the listed appliances will be required to provide for the flexibility and expandability also called for in the definition of need.

In order to determine what data rate will be required to support the devices listed in the needs analysis each device was examined to determine how that device is used by the average consumer. Based on this review each device was assigned the number of bits that will be required to support the device during a ten second period. Then the survey results were reviewed to determine how many of each device are found in the average home. The bits per ten seconds required to support a device type is then determined by multiplying the average number of devices by the number of bits required to support that device. The number of bits required to support the device is then multiplied by two to adjust for the affect of the system overhead bits. The results of these calculations done for each device is tabulated in table 4.2.

The total number of bits per ten second period required to support the devices called for in the needs analysis is 7956. The total 7956 is then divided by ten to give the per second data rate of 795.6. The bit rate per second is rounded up to 796 bits per second.

Table 4.2 Communication Requirements Of Home Appliances

	Number Of Devices	Information Bits Bits Per 10s	Overhead Bits Bits Per 10s	Total Bits Per 10s
TV	2	320	400	1440
Stereo	2	320	340	1440
Answering Machine	1	80	100	180
VCR	1	320	400	720
Thermostat	1	32	40	72
Coffee Maker	1	32	40	72
Home Security	20	32	40	1440
Lighting	20	32	40	1440
Smoke Detector	2	64	80	288
Home Intercom	10	32	40	720
Conventional Oven	1	32	40	72
Microwave Oven	1	32	40	72
Total	62	—	—	7956

The definition of need indicated that the expandability of the home automation system is very important. In order to insure that the capability to expand exist, the required data rate is doubled. After the data rate is doubled it is increased by eight bits per second in order to produce the required bit rate of 1600 bits per second.

Response Time

The needs analysis indicated that response time of the home automation system must be less than one half of a second. Assuming that a packet of data will be sixty-four bits (32 information bits, 40 overhead bits), the amount of time it will take to transmit a packet at the 1600 per second bit rate is :

$$\frac{\text{72 Bits}}{\text{Packet}} \times \frac{\text{Second}}{\text{1600 Bits}} = \text{.04500 Seconds}$$

If the worst case situation is considered where it takes four packet lengths to actually transmit a single packet then the amount of time allowed for a device to receive a packet and respond to it is:

$$\text{Required Response Time} - (\text{Packet Transmittal Time}) \times 4 = \text{Required Processing Time}$$

$$0.5\ \text{Seconds} - (0.04500\ \text{Seconds}) \times 4 = 0.320\ \text{Seconds}$$

The required processing time of any automated device after receiving a packet is .320 seconds.

Connectivity

The needs analysis indicated that it was important that the home automation system allow for appliances in all rooms of the house to be automated. In order for this to happen the communication medium must extend into every room in the home.

If the communication medium is wireless then one hundred percent connectivity will require enough transmitters and receiver to reach every room in the home. Depending on the size of the home the number of required transmitters and receivers will change.

If the communication medium relies on a cable then the requirement can be defined in terms of the number of feet of cable that will be required to reach every room in the home. Given the average home 300 feet of cable will be required to reach every room in the home.

Aesthetics

The results of the survey indicated that it was very important that the home automation system not affect the aesthetics of the home.

Reliability

The reliability of communications within the home automation system is very important. As indicated by the needs analysis consumers felt it was very important that commands issued to through the system not be misinterpreted. In order to insure this an error detection scheme must be utilized to minimize the probability of a signal being received incorrectly.

In order to determine what the error detection requirements will be, the probability of a single bit error occurring must be known. Unfortunately the probability of a bit error depends on a number of variables that have not been determined at this point in the design process. Among those variables are the noise levels that will vary depending on the communication medium that is used, its surrounding environment, and the signalling voltages and technique that will be used to transmit home automation data.

Since the probability of bit error cannot yet be exactly be determined, an upper bound will be placed on the probability of a single bit error. The upper bound on the probability of a single bit error will be placed at 10^{-4} (i.e. $P_e = 10^{-4}$). Thus all communications that take place must do so with a probability of bit error of less than 10^{-4}. The chosen probability of bit error is not a very stringent requirement and is more a worst case to insure that the error detection scheme is designed to work in a less than favorable environment. This is necessary because of the wide range of settings that an American home is found.

In order to determine what the error detection requirements should be, a value must be chosen to define reliable communications. The value that will be used is less than one frame per year interpreted incorrectly given maximum throughput use of the system. Less than one frame received in error will provide a system that appears error free

With the given probability of bit error ceiling, the frame length, and the required incorrect frames per year the operational requirements can be determined for the error detection scheme. The first value that must be calculated is the number of frames that will be transmitted each year at maximum throughput. The maximum amount of frames per year is given by:

$$\frac{1600\ \text{bits}}{\text{Second}} \times \frac{60\ \text{Seconds}}{1\ \text{Minute}} \times \frac{60\ \text{Minute}}{1\ \text{Hour}} \times \frac{24\ \text{Hours}}{1\ \text{Day}} \times \frac{365\ \text{Days}}{1\ \text{Year}}$$

$$= 50.457 \times 10^{+9} \ \frac{\text{bits}}{\text{Year}}$$

$$\frac{\text{Frames}}{\text{Year}} = 50.457 \times 10^{+9} \ \frac{\text{bits}}{\text{Year}} \times \frac{1\ \text{Frame}}{72\ \text{Bits}}$$

$$= 700 \times 10^{+6} \ \frac{\text{Frames}}{\text{Year}}$$

With 700 x 10^{+6} frames for year the maximum likelihood of a word being interpreted incorrectly is given by.

$$\frac{\text{Frame Error}}{\text{Year}} < \text{One}$$

$$\frac{700 \times 10^{+6}\ \text{Frames}}{\text{Year}} \times P_{(\text{frame error})} = \frac{\text{Predicted Frame Error}}{\text{Year}} = 1$$

$$P_{(\text{frame error})} = \frac{1}{700 \times 10^{+6}} = 1.4286 \times 10^{-9}$$

Given the likelihood of a frame being interpreted incorrectly, the requirements for the error detecting code can be defined. The following equation for the probability of a word being interpreted incorrectly can be solved for the number of bit errors that the error detection code must be capable of detecting.

p = the pobability of a bit error = 10^{-4}

d = the number of bit error that can be detected per frame

n = the number of bits per frame = 63

$P_{(\text{frame error})} = 1.4286 \times 10^{-9}$

$$P_{(\text{frame error})} = \sum_{i=d+1}^{63} \binom{n}{i} (p)^{i} (1-p)^{n-i}$$

When (n) (p) << 1 Then

$$P_{(\text{frame error})} \approx \binom{n}{d+1} (p)^{d+1} (1-P)^{n-(d+1)}$$

$$1.4286 \times 10^{-9} > \binom{63}{d+1} (10^{-4})^{d+1} (1 - 10^{-4})^{n-(d+1)}$$

Solving For "d" Yields:

When d = 3, $P_{(\text{frame error})} = 39.473 \times 10^{-9}$ (larger than 1.4286×10^{-9})

When d = 3, $P_{(\text{frame error})} = 0.059 \times 10^{-9}$ (less than 1.4286×10^{-9})

<u>Thus " d " must be chosen to be "3".</u>

Based on the above calculations in order to meet the reliability demands placed on the home automation communications, the error detecting scheme must be able to detect three bit errors out of each frame.

Availability

Examination of the current home automation industry indicates that there are currently numerous home automation systems under development. The research also indicates that all of the systems will not be available in the next two years. In order to take advantage of the opening in the market the system should be available in one year. In order to allow the system to be available in one year as much off the shelf technology as possible should be used.

Ease Of Use

As stated in the needs analysis, a high level of user friendliness is very important to consumers interested in purchasing a home automation system. Consumers who participated in the home automation demonstration had the easiest time interacting with the controlling computer when the controlling computer took advantage of a menu driven system. In addition the consumers responded most positively to a menu system when it took advantage of high resolution graphics, sound affects and a pointing device such as a mouse. Based on these results it is seen as imperative that the human machine interface employed with the control computer be as user friendly as possible and that it employ such things as menus based on high resolution graphics, sound affects and pointing devices

Chapter 5: Preliminary System Analysis

Introduction

The preliminary systems analysis stage of the systems engineering process is where the system operational requirements are reviewed, and a method of meeting these requirements is determined. The first step of the preliminary system analysis is to review the of feasible alternative solutions form the feasibility study. (1,p46) These alternative solutions are based on the various technologies that are available or could be made available.

Once the design alternatives have been suggested, the next step is to determine which of these alternatives is the most suitable solution. Determination of which design is best can only be done after an evaluation criteria has been defined. The evaluation criteria can be defined as a set of parameters that are important to the system makeup. The following are parameters that are often used to evaluate a system: cost effectiveness, reliability, safety, system performance, or environmental safeness. (1,p.46) Once the evaluation criteria is chosen it can then be used to compare each of the design alternatives.

The three design choices that will be reviewed in the preliminary system analysis are: which communication medium should be chosen, what type of controlling computer should be chosen, and which LAN protocol should be used. Each of these design choices will be evaluated based on a set evaluation criteria. The evaluation criteria will be based on the System Operational Requirements. The results of each of the design choice review will be recommended design approach. The recommended design approach is the design choice that is most appropriate to proceed with based on the operational requirements.

Communication Medium

The candidates for the home automation communication medium are: coaxial cable, infrared, optical fiber, home power bus. These four design choices will be reviewed based on the following criteria: cost, connectivity, data rate support, aesthetics and the availability of the required technology. The following paragraphs give a more complete explanation of the evaluation criteria.

Cost

The cost criteria of the communication medium will me made up of two components. First and possibly the most significant will be the material cost. In the case of a system that relies on wiring the material cost will be the cost of the wire and any other materials required to adapt the wire to a home. The second component of the communication medium cost will be the installation cost. Installation cost will include any materials and man hours involved in the installation of the medium.

Connectivity

Connectivity is simply the capability of the communication medium to reach every room in the house and the capability of the medium to reach every appliance in a room. A communication medium that reaches every room in the house but is unable to reach to certain locations in the room has good but not perfect connectivity. The ability to automate devices in the home will depend in large part on the ability of the home automation system being able to contact the device that is to be automated. Thus it is crucial that the communication medium have good connectivity. A communication medium that has many good features, but poor connectivity, will likely be rejected.

Data Rate Support

Data rate support is the capability of the communication medium to provide a great enough bandwidth to support the required communication rate. The required data rate as specified by the System Operational Requirements is 1600 bits per second.

Aesthetics

Is the perceived effect that the installed communication medium will have on the appearance of the home.

Availability

The System Operational Requirements call for the system to be available for sale within one year. Based on this requirement it is fairly important that the chosen communication medium and all associated hardware be easily available *off the shel.*

Coaxial Cable Evaluation

A coaxial cable based system would consist of coaxial cable placed in the walls of a home. In order to provide complete connectivity the cables would be required to be installed throughout the entire home.

Coaxial Cable - Cost

There will be three components to the cost of a coaxial communication medium. The first component is the actual cost of the 300 feet of coaxial cable that will be required to wire the average home. The second component will be the connectors, wall sockets, splicers, and other associated hardware required to wire a home with coaxial cable. The third component of the coaxial cable cost will be the cost of the man hours associated with installing the coaxial cable into a home.

The cost of 300 feet of coaxial cable is $100.00. The cost of the wall panels, connectors, splicers, and other hardware associated with installing 300 feet of cable in the average home will be $324.00. The labor cost associated with installing the coaxial cable throughout a home will be $600.00.

Based on the information above the average cost of a coaxial communication bus will be 1024.

Coaxial Cable - Connectivity

A communication bus using coaxial cable will be capable of achieving a high level of connectivity. After a home has been wired with enough coaxial cable it should have no problem reaching any appliance in the home.

Coaxial Cable - Data Rate Support

Coaxial cable can support data rates of up to 10Mbps. The required data rate for the home automation system is only 1600 bits per second. Thus if coaxial cable is chosen as the communication medium it will very easily be able to live up to the System Operational Requirements.

Coaxial Cable Aesthetics

Once installed in the walls of a home the only visible change to the homes appearance will be the wall sockets which provide access to the coaxial cable. These wall sockets will very much like telephone or cable TV sockets. The coaxial cable sockets could be placed at a height that would allow them to easily be hidden by furniture. Thus the coaxial cable communication bus would affect the homes aesthetics very little.

Coaxial Cable - Availability

Coaxial cable and its associated hardware is well documented as a good communication medium for local area networks. All required hardware would be available immediately *off the shel.*"

Infrared Bus Evaluation

A infrared communication bus would rely on a series of repeaters that relayed the home automation signal to all rooms of the house. Each appliance would be required to have a infrared receiver and transmitter built in to allow it to communicate on the home automation LAN.

Infrared Bus - Cost

A household infrared bus will rely on enough infrared transceivers (transmitter/receiver) placed throughout the home in order to allow a line of sight link between all rooms in the house and all automated devices in a room. The cost of such a system would consist of the hardware required to implement the system, and the labor charge required to install the system. The cost of infrared traceivers is relatively low with an individual cost of less than ten dollars. Unfortunately to insure as high as possible a level of connectivity numerous transceivers would have to be used. Increasing the number of transceivers not only increases the cost of the hardware but also the cost of having the hardware installed. Since the infrared system will rely on *line-of-sigh*, holes would likely need to be cut into the frames of household room doors. This will be required in order to protect the *line-of sight* link when a door is closed. Even with these drawbacks the cost of an infrared system would still be relatively inexpensive. The cost to install an infrared bus in a average home would likely be less than $300.00

Infrared Bus - Connectivity

Connectivity of an infrared bus will require that the line of sight for each transceiver and each appliance be protected. Infrared links are used in LAN systems to provide line-of sight links between buildings or occasionally in an office environment where a line-of-sight between transceivers is easier to guarantee. Guaranteeing a line-of-sight between all transceiver in a home would be difficult. Most homes are broken into a series of rooms and hallways. This would require a complicated system of transceivers to insure connectivity with each room. Also the line-of- sight to an individual appliance would always be subject to a person or object being placed in between the transceiver and the appliance. Something as simple as a jacket or shirt placed on top of an appliance could block the receiver on an appliance. Based on the above discussion the connectivity level of a infrared bus would be low.

Data Rate Support

Infrared links support data rates of up to 3 Mbps. The required data rate for the home automation system is only 1600 bits per second. The current infrared technology would easily match the system operational requirements for data rate.

Aesthetics

The effect that an infrared bus would have on the aesthetics of a home would not be severe but would be greater than the effect of a coaxial bus. An infrared bus would require the installations of transceivers throughout the home. Due to the line-of-sight requirements of such a system the transceivers would have to be visible on the walls of the home. The infrared bus would have a noticeable effect on the aesthetics of a home

Availability

There is technology available today that is suitable for use in local area networks. This technology is designed for the office environment and would have to be modified for use in the home. The adaption of this technology would take less than the year requirement.

Optical Fiber Evaluation

A fiber optic cable based system would consist of fiber optic cable placed in the walls of a home. In order to provide complete connectivity the cables would be required to be installed throughout the entire home.

Fiber Optics - Cost

The cost of a fiber optic communication bus in the home will be made up of three components: the cost of the cable itself, the cost of the associated hardware, and the cost of having the cable installed. Fiber optic cable is available at about twice the price of coaxial cable. The price of three 300 feet would be approximately $200.00. The cost of the hardware that is required to place a optical fiber net in the home would cost over $600.00.

The task of installing fiber optics in the home could not be carried out by the average home electrician. Fiber optic technology is relatively new, and the task of installing the cable would have to be carried out by technicians trained to work with fiber optics. The cost of installing fiber optic cable behind the walls of a home would cost over $1,000.

The total cost of a fiber optic communication bus in the home would cost more than $2,000. This is twice the price ceiling placed on the entire home automation system.

Fiber Optics - Connectivity

A communication bus using fiber optic cable will be capable of achieving a high level of connectivity. After a home has been wired with enough fiber optic cable it should have no problem reaching any appliance in the home.

Fiber Optics - Data Rate Support

Fiber optics cable can support data rates over 10Mbps. The required data rate for the home automation system is only 1600 bits per second. Thus if fiber optic cable is chosen as the communication medium it will very easily be able to live up to the System Operational Requirements.

Coaxial Cable Aesthetics

Once installed in the walls of a home the only visible change to the homes appearance will be the wall sockets which provide access to the fiber optic cable. These wall sockets will look very much like telephone or cable TV sockets. The fiber optic cable sockets could easily be placed at a height that would allow them to be hidden by furniture. Thus the fiber optic cable communication bus would affect the homes aesthetics very little.

Fiber Optics - Availability

although the technology is still developing, the hardware necessary to install a fiber optics bus in the home is available immediately.

Home Power Line Bus

A home power line communication bus would rely on all communications between a central computer and automated appliances to be carried out over the home power line. The signal will be modulated at a frequency which does not interfere with the normal 60 Hz power signal. Any device that is attached to the home automation system will receive both its power and its control signals through its power cord.

Home Power Line - Cost

All modern homes already have copper cable power lines in their walls. There would be no modifications necessary to the home power bus in order to make it capable of acting as the home automation bus. The only added cost that must be considered are the added electronics that would have to added to each device on the bus in order to allow its logical elements to interact with a line carrying a 110 VRMS signal without being damaged. These electronics would consist of a simple band-pass filter built out of components capable of withstanding the high power signal (see Appendix A). Once a device has been isolated by the bandpass filter from the high power signal normal electronic components will be used to receive or transmit the control signals. The added cost of the high power electronic components would be less than three dollars per device. If the home power bus is chosen as the best suited communication medium then the added three dollars must be considered when evaluating the devices used to interface with the home power line.

Home Power Line - Connectivity

In most homes in America power sockets are available in every room in the house. Also most appliances in the home are powered off of the home power bus, and access to the power bus will already have been established. Thus the connectivity of a communication bus based on the home power line will be excellent.

Home Power Line - Data Rate Support

The operational requirements for data rate is 1600 bits per second. The electronics industry association indicates that the home power line can support a data rate of 10,000 bits per second. (13) Thus a communication bus based on the home power line will be capable of supporting the required data rate.

Aesthetics

All modern American homes already have copper power cables installed in their walls. Thus the communication medium will not change the aesthetics of the home. Any device that is not normally powered by the home power signal will have an additional power cord that it would not require if it was not attached to the home automation bus.

Availability

The technology required to implement a home automation bus based on the home power line is available off the shelf. The author built a simple prototype that allowed two devices to communicate over the home power line (see Appendix A)

Communication Medium Evaluation

Table 5.1 summarizes the results of the above analysis.

Table 5.1 Communication Medium Comparison

	Cost	Connectivity	Data Rate Support	Home Aesthetics	Availability
Coaxial Cable	Cable Hardware Installation $1024.00	Excellent	10 Mbps	Wall Sockets In Each Room Small Impact	Immediately Available
Infrared Link	Tranceivers Hardware Installation $300.00	Poor	3 Mbps	Tranceivers Placed Throughout Home Medium Impact	Some Development Required
Fiber Optics	Cable Hardware Installation >$2,000.00.	Excellent	> 10Mbps	Wall Sockets In Each Room Small Impact	Immediately Available
Home Power Bus	The cost of the Bus would be zero.	Excellent	10 Kbps	No Impact	Immediately Available

The communication medium that best matches the requirements set forth in the System Operational Requirements is the home power bus. The home power bus is the least expensive, provides connectivity as good as coaxial cable and fiber optics, supports the data rate requirements, relies on immediately available technology, and has the least effect on the home aesthetics. Coaxial cable was a close second but the cost of installing a coaxial network in the home ate up too much of the total system price ceiling of $1,000.00. Fiber optics offers many excellent characteristics but its capabilities and price are over kill for the home automation system. Infrared is not suited to the architecture of the average home.

Computer Evaluation

There are two design choices for the roll of controlling computer. They are a dedicated special purpose computer, or the general purpose PC found in many homes. The dedicated controlling computer would require that a computer complete with CPU, monitor, data entry device, and software be developed for the purpose of controlling the home automation system. The general purpose PC option would rely on developing the hardware and software that will allow a home PC to act as the controlling computer for the home automation system.

The controlling computer design option will be evaluated using the following criteria: hardware cost, software cost, user friendliness, and availability. hardware cost will reflect the actual cost of the hardware and the shared cost of developing the hardware. Software cost will also reflect both material cost and development cost. User friendliness will be the measure of the systems capability to be developed in such a way as to make it easy for consumers to use. Flexibility will measure the controlling computers ability to be upgraded or change based on the advances in home automation technology. Availability will be a measure of whether or not the development of the controlling computer will impact the requirement that the total system be ready for sale within one year.

Dedicated Computer Evaluation

The dedicated computer will consist off the following component: CPU, color monitor, communication medium interface hardware, operating hardware, and user interface hardware.

Dedicated Computer - Hardware Cost

In order to have a dedicated computer system for the home automation system, the consumer will have to pay for the cost of the dedicated equipment and its development. The operational requirements call for a controlling computer that takes advantage of high resolution graphics, sound affects, and advanced pointing devices. Thus the dedicated controlling computer will be required to have high resolution graphics, sound capability, and a mouse or other pointing device. In addition to these requirements the dedicated controlling computer must have a disk drive type device that will allow new operating information to be loaded into the computer as new appliances are added to the home automation system. Given the state of todays technology a dedicated controlling computer with all the necessary hardware to interface both with humans and the communication bus can be made available to the consumer for less than $900.00.

Dedicated Computer - Software Cost

The software for the controlling computer will be required to control the automation of the home, control the interface with a system user, control the use of the communication bus, and allow for the initialization of the system. Often software is priced higher than normally would be necessary in order to make up for the loss due to a large number of illegal copies of a software package that will be made. In the case of a dedicated special purpose computer the software will only be capable of running on the special purpose machine and the software will be of no use to a person without the other equipment needed to operate the home automation system. based on the above discussion the home automation software for the dedicated computer can be made available to the consumer for $200.00.

Dedicated Computer - User Friendliness

The dedicated computer will come equipped with high resolution graphics, sound affects, a color monitor, a keyboard, and a pointing device. Given these features a home automation system that relies on a dedicated computer will be capable of having a high degree of user friendliness.

Dedicated Computer - Availability

The technology necessary to develop a dedicated computer and associated software is immediately available.

General Purpose Personal Computer Evaluation

The second design option for controlling computer relies on the use of a normal personal computer. In order to take advantage of the personal computer as the controlling computer for the home automation system it will be necessary to design hardware that will allow the PC to interface with the communication bus. The hardware needed to communicate with the communication bus would likely come in the form of a card that would be compatible with the card slots in the back of most personal computers. Software would also be required that would allow the PC to interact with a home automation user and to allow the PC to control the home automation system. In order to take maximum advantage of the available market both the hardware and software would have to be designed for the two most popular personal computer types (IBM, and Apple).

General Purpose Personal Computer - Hardware Cost

The only hardware cost associated with allowing the personal computer to act as the controlling computer would be the cost of the of the hardware that will allow the PC to interface with the communication bus. As stated earlier the interface hardware would likely come in the form of a card compatible with the card slots in the back of both IBM's and Apple computers. Both IBM and Apple computers already come with high resolution color graphics, disk drives, sound capabilities, disk drives, keyboards, and pointing devices (mouse). Thus there would be no other hardware cost besides the communication bus interface card. A card designed to allow a PC to interface with the home automation communication bus could be developed and made available to a consumer for less than $100.00.

General Purpose Personal Computer - Software Cost

The software for the controlling computer will be required to control the automation of the home, control the interface with a system user, control the use of the communication bus, and allow for the initialization of the system. Development of home automation software for a PC based controlling computer would be less expensive than developing it for the dedicated computer due to the fact that there are numerous software development aids for developing software for both the IBM and Apple personal computers.

Often software is priced higher than normally would be necessary in order to make up for the loss due to a large number of illegal copies of a software package that will be made. The illegal copying of the home automation software will not be a factor though because in order to use the home automation software a consumer will also have to purchase the home automation hardware. Based on the above discussion the home automation software for the PC can be made available to the consumer for $75.00.

General Purpose Personal Computer - User Friendliness

The average personal computer has numerous features that will optimize its ability to be used as a user friendly controlling computer for the home automation system. Due the large amount of competition amongst computer manufacturers and the advances in computer technology, consumers have been able to purchase very powerful computers for their homes. These computers are very fast, they have color high resolution graphics, sound affects, and high-tech. keyboards. All of these features make todays PC very capable of supporting a user friendly environment. Also the software programming aides available to help programmers of IBM's and Apples make the development of user friendly software much efficient.

General Purpose Personal Computer - Availability

The technology required to develop the computer card that will allow a PC to interface with the home automation system is immediately available.

Controlling Computer Design Choice - Evaluation

Due to the advances in computer technology, mass production, and competition amongst computer manufacturers the personal computers available to the American consumers are very powerful and inexpensive. Figure 5.1 shows how that there are almost thirty million homes with computers in them, and that the average clock speed of the average computer sold is 20 Mhz.

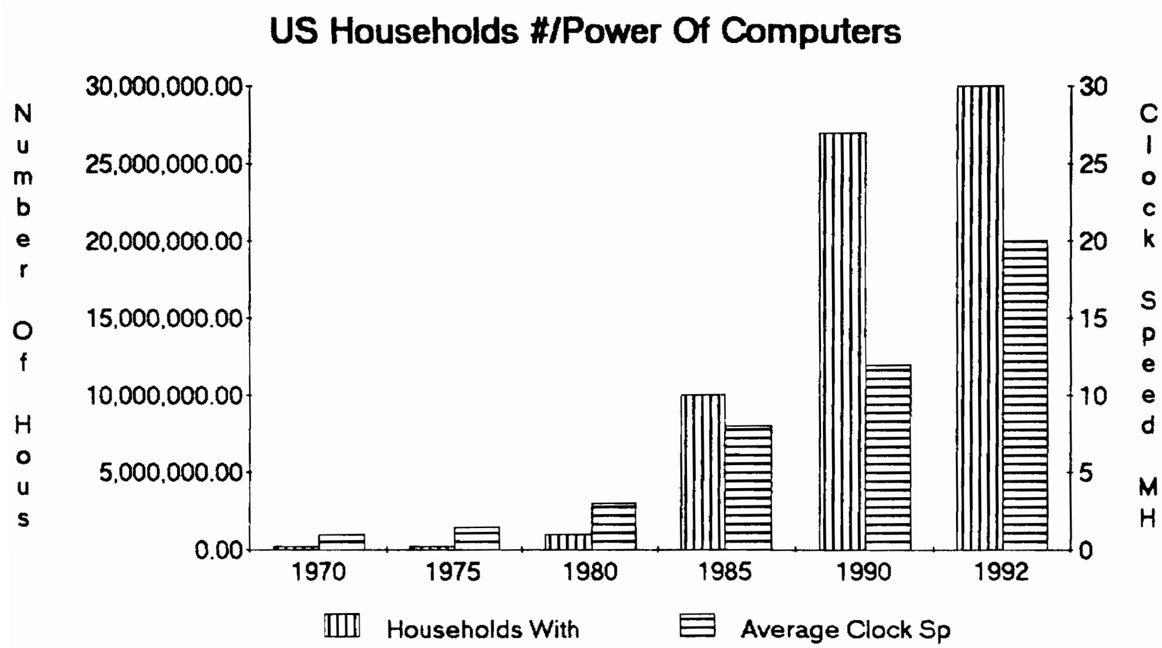


Figure 5.1 The Number And Power Of The American Household PC

It would be impossible to produce a dedicated controlling computer that would be able to compete with all of the advantages of the personal computer without breaking the $1,000.00 price ceiling. Based on this analysis the choice for controlling computer will be the personal computer.

Local Area Network Protocol Evaluation

In order to allow numerous devices to communicate over the home automation communication bus there will have to be a set of rules that allows fair access to the bus. The rules that define how communication will be carried out over local area network are known as the local area network protocol. There has been a great deal of research done into the best way to develop a LAN protocol. It will be less expensive and more efficient if one of the already developed guidelines is used in the development of the home automation LAN protocol. The two protocol types that were identified by the feasibility study as candidates for the home automation system are the Token Bus, and Carrier-Sense Multiple Access With Collision Detect (CSMA/CD). Both of these protocol types are well suited when the LAN will be configured as a bus. Due to the nature of the home power lines the home automation bus will be configures as a bus. The following paragraphs will give a short description of the two protocol types and then evaluate which would be best to use in the home automation system.

CSMA/CD

CSMA/CD is the most commonly used protocol when the communication medium is configured as a bus. (3, p156) When a device attached to a CSMA/CD LAN wishes to transmit data over the LAN it listens to the LAN for the presence of another devices signal already on the LAN. If the listening device does not detect a signal already on the LAN then it transmits its signal. If the listening device detects that there is a signal on the LAN then it continues to listen until the LAN is free. (3, p158) When the listening device detects that the LAN is free it then waits a set period of time. This set period of time is to insure that the device that just received the transmitted message has time to transmit back an acknowledgment packet. After waiting a set period of time the device that was listening transmits its information.

When a device transmits a message, whether or not it originally found the LAN free or had to listen and wait, another device on the LAN may transmit its message at approximately the same time. If this happens then both the devices that are transmitting will detect the collision of the two signals on the LAN.. When a collision is detected each device that was attempting to transmit waits a random period of time and then starts the original transmit algorithm again. The period of time that a device waits is random to insure that both devices that collided do not both wait the same period of time and eventually produce signals that will again collide.

Token Bus

The Token Bus is a relatively new LAN protocol type that is based on the better known Token Ring protocol. (3, p165) The Token Bus technique is more complex than the CSMA/CD technique. Devices on a Token Ring LAN are configured in what is known as a logical ring. Each device on the LAN knows the identity of the device before and after it in the logical ring. The physical location of each device does not matter just the logical ordering of the devices

Access to a Token Bus LAN is controlled by the passing of a token frame. When a device on the LAN receives the token frame it has sole access to the LAN for a set period of time. A device which has the token can either use all or part of its time on the LAN or pass the token to the next device on the LAN. In this way each device gets access to the LAN and there is no contention for the use of the LAN.

LAN Protocol Evaluation

The two choices for LAN protocol will be evaluated based on: their ability to allow the response time requirement to be met, and there overall capability to efficiently run a home automation LAN.

In order to best determine which type of LAN protocol would be best for the home automaton system an evaluation must be made as to what the traffic will most likely be like on the home automation LAN. The traffic on the LAN will likely be bursty there will be periods of time where there is no traffic followed by short period of time where there is heavier LAN traffic. There will likely be periods of time when there are no appliances that need to transmit data on the home automation LAN. If there is no demand by the appliance for the use of the net and there are no commands being issued by the operator of the home automation system then there will be no traffic on the LAN. Other times numerous appliances may need to access the LAN at the same time, and the operator of the system may also be issuing commands to a device an the LAN. The LAN protocol that will work most efficiently given this type of traffic will be best suited for the home automation system.

Stallings in his book Local Networks list the values given in table 5.2 as the positive and negative aspects of CSMA/CD and Token Bus

Table 5.2 CSMA/CD -VS- Token Bus

	Advantages	Disadvantages
CSMA/CD	- Simple Algorithm - Widely Used - Fair Access - Good Performance at Low to medium loads - Good with burst traffic - Good with interactive applications	- Collision detection requirements - Fault diagnosis problems - Minimum packet size - Poor performance under very heavy load - Biased to long tranmissions
Token Bus	- Excellent throughput performance - Tolerates large dynamic range - Regulated access - Good for stream traffic	- Complex algorithm - Unproven technology

CSMA/CD works well when devices on the LAN are not transmitting most of the time. When a device does have data to transmit it can often grab immediate access to the LAN. Stalling states that CSMA/CD is well suited to interactive application type traffic. The home automation system can be described as an interactive system. Most of the problems associated with the CSMA/CD exist only when the traffic is very heavy, or when stations are very far apart. The home automation system will not often have very heavy traffic, and by LAN standards the devices will never be far apart.

Token Bus systems are required to deal with the maintenance of the token frame even if no devices on the LAN require access to the LAN. Also if a device has data to transmit it must wait until the token is passed to it even if no other device on the LAN has data to transmit. Token bus also requires a great deal of maintenance from the LAN device that controls the LAN. In the case of the home automation system this would require the PC to constantly administer the LAN even when no devices have data to transmit. Also the addition and subtraction of devices to the LAN becomes much more complicated. When a device is removed from the LAN it must first inform the rest of the devices so that link in the chain of devices on the LAN that will be broken when the device is removed can be patched. Thus if a device on the home automation bus is turned off or removed it could cause an anomalous situation. Also when devices are added to the LAN the rest of the devices on the LAN must open up a space for the device in the chain of devices. These requirements that are placed on a Token Bus system would require that the devices attached to the LAN be sophisticated enough to cope with the management of the LAN. This would increase the cost added to each device as the producer of consumer electronics and appliances make their products home automation compatible.

The required response time that is given in the System Operational Requirement is .5 seconds. That is when a command is issued by the operator of the home automation system the device being commanded must be able to respond in less than .5 seconds. The amount of time that it takes for a device to respond will depend in part on how long it takes for a device to get access to the LAN. With CSMA/CD often a device will gain immediate access and at worst it will have to wait the amount of time required for a few other devices to transmit in front of it.

Given the architecture and use requirements of the LAN it is unlikely that a device will have to wait more than four transmittal periods to gain access to the LAN. This would allow the CSMA/CD to meet the response time set in the System Operational Requirements.

If Token Bus is used a device attempting to gain access to the LAN will be required to wait for the token frame to be passed to it. Even if no other device on the LAN has data to transmit, a device may have to wait for each device to pass the token before it gains access to the LAN. This delay would prevent a device from meeting the .5 second response time.

Based on the above discussion the CSMA/CD should be used as the guide in the development of the home automation protocol.

System Specifications

After the evaluation carried out in the Preliminary system Analysis a baseline description of the home automation system can be given. The system will be controlled by either an IBM, or Apple computer. Communications between the controlling computer and appliances in the home will be carried out over the home power line. The communication protocol for devices communicating on the power line will be based on the CSMA/CD protocol. The system will be designed to handle up to 124 devices, and communications will be carried out at 1600 bits per second.

The above system specification are the result of the conceptual design. The results of the conceptual design stage are the starting point for the preliminary design for the home automation system.

Chapter 6: Functional Analysis

Preliminary Design Introduction

The technical base provided by the conceptual design phase of the system engineering process is the starting point for the preliminary system design phase. The purpose of the preliminary design phase is to translate the system level requirements put forth by the conceptual design phase into a more technical and quantitative set of design requirements. (1,p.55) The final result of the preliminary design phase is an overall system design configuration. This overall system design configuration is then used as input to the detail design and development phase, which in turn will produce the final home automation system design.

The major steps involved in the preliminary design phase will be discussed. The first step is the system functional analysis, where the set of requirements put fourth during the conceptual design phase are turned into a set of functions or discreet actions that must be accomplished in order to meet the given requirements. (1,p.55) The second step in the preliminary design is the synthesis and definition stage. During this portion of the preliminary design phase, the determination is made as to what design configuration will best satisfy the specific requirements given to each piece of the system by the allocation of requirements step.

System Functional Analysis

The functional analysis stage of the systems design process seeks to identify design requirements by breaking the total system into a series of hierarchical functions. The functions defined in the functional analysis are those needed to achieve the goals of the system. Input to the system functional requirements is provided by the system operational requirement. The functions defined by this analysis can be carried out by hardware, software, or human operator. Blanchard (1,p.56) states that the functional analysis step in the system design process ensures the following:

> 1. That all facets of system development, operation and support are covered. This includes design, production/construction, test, deployment, transportation, training, operation, and maintenance.
> 2. That all elements of the system (e.g., prime equipment, and support equipment, facilities, personnel, data, software, etc.) are fully recognized and defined.
> 3. That means of relating equipment packaging concepts and support requirements to given functions is provided. This identifies the relationship between the need and the resources required to support that need.
> 4. That proper sequences and design relationships are established along critical design interfaces.

The task of translating the system operational requirements into a hierarchic series of functions is facilitated through the use of functional flow diagrams. Functional flow diagrams are a series of diagrams that start by defining the system in terms of a few broad functions and then get more specific until the last set of diagrams details component level functions of the system. (1,p.57) Each more specific diagram in the series of functional flow diagrams can be traced back to a box (a box is used to define a function) in a less specific diagram. In this way each of the functions in the original broad diagram is broken down into a group of more specific diagrams. Then each of the functions in the more specific diagram are broken down into even more specific diagrams. This continues until the boxes in the diagrams are representative of the functions of the individual components of the system.

The functional flow diagram is a critical tool used in the systems engineering process. The diagrams provide among other things a means for the critical exchange between the conceptual design phase to the preliminary design phase. The diagrams allow the designer to take the conceptual design requirements and transfer them into functional terms. A design team can work with the functional flow diagrams until they represent a functional flow that will match all of the system design requirements.

The functional flow diagrams provide an efficient organizational tool. The flow diagrams allow for the easy assignment of tasks to various design groups. A design group can be assigned the task of investigating various design that may satisfy one or more of the functions represented by the boxes in a functional flow diagram.

A design team working from a functional flow diagram on the design of one of the functions will have the added advantage of being able to easily determine where their work must fit into the overall flow of the system. This understanding will lead to a better design because engineers will more clearly understand the flavor of what they are attempting to accomplish

The functional flow diagrams also serve as a guide mechanism to help insure that as a design progress it is meeting all of the requirements assigned to it. If halfway through a design some of the functions in the functional flow diagrams are not represented, the design will need to be reevaluated

The following set of functional flow diagrams are for a total home automation system. Components other than those directly associated with the communication bus are included to insure that their relation to there interface with the communication protocol is captured. The exact devices that will be required to interface with the communication bus cannot be exactly predicted; thus a set of standard devices is assumed. The functions represented for the chosen devices will be the dame irregardless of the devices that are chosen. the devices that are included in the sample set are: a home thermostat, a home intercom, a television interface, a handheld remote control, and household sensors. The devices chosen in the sample set are all devices that were specified in the needs analysis:

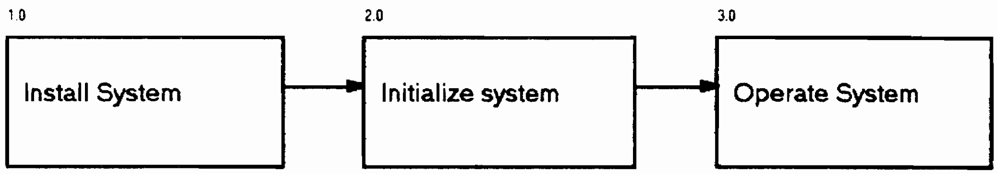
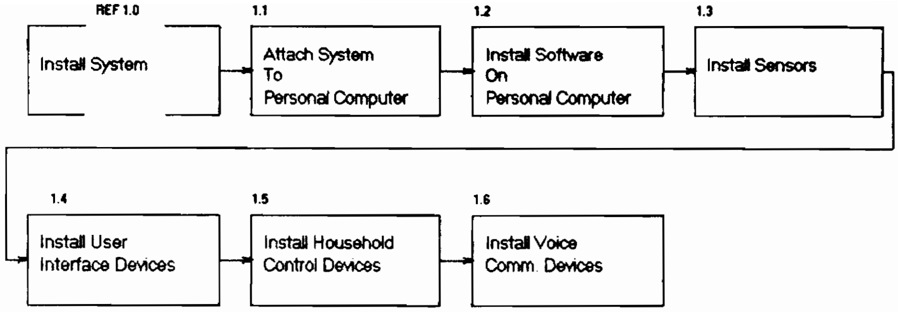


Figure 6.1 Home Automation System Functional Flow Diagram



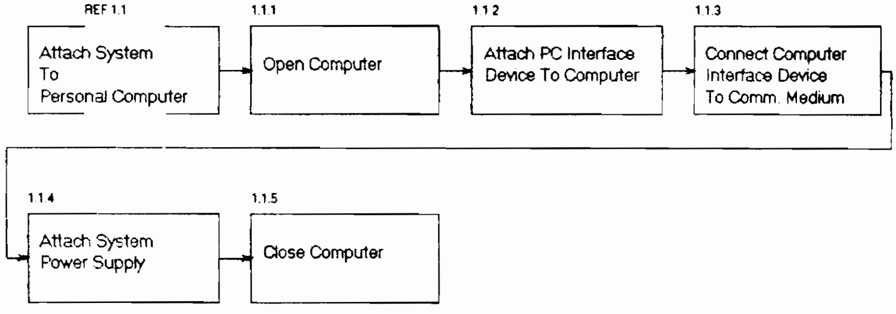


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

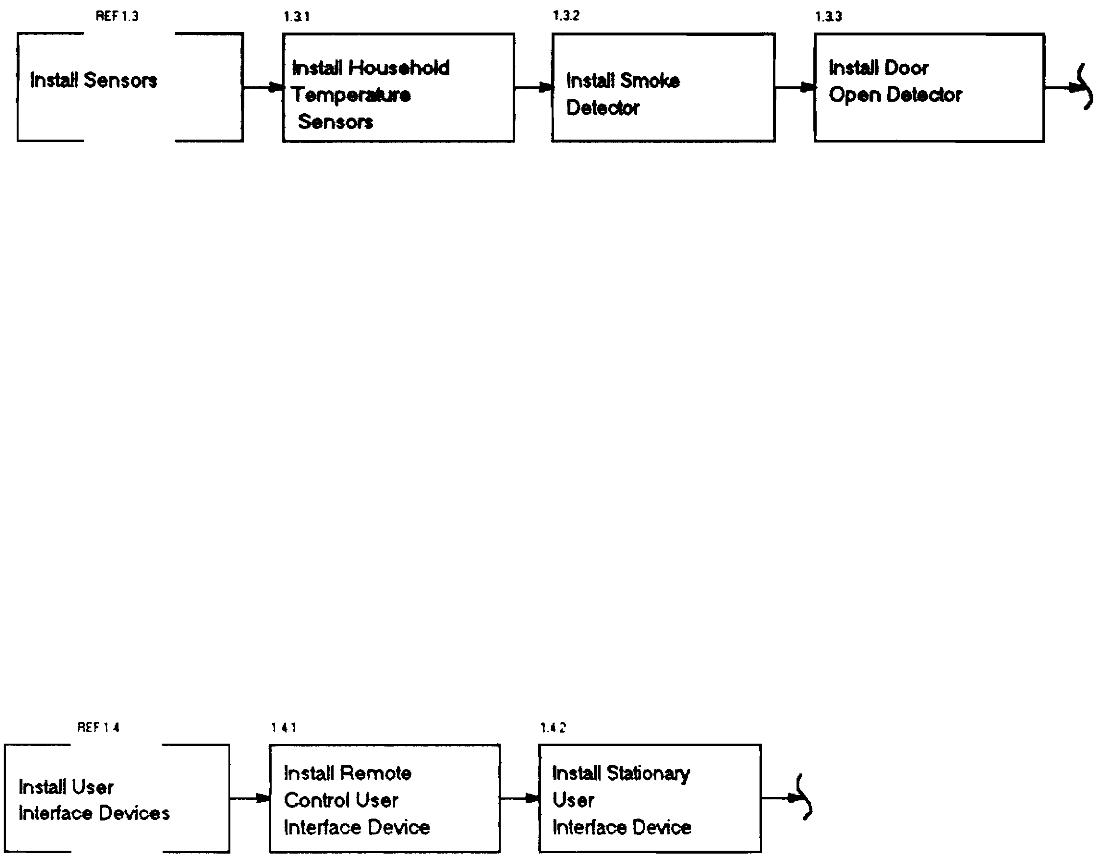


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

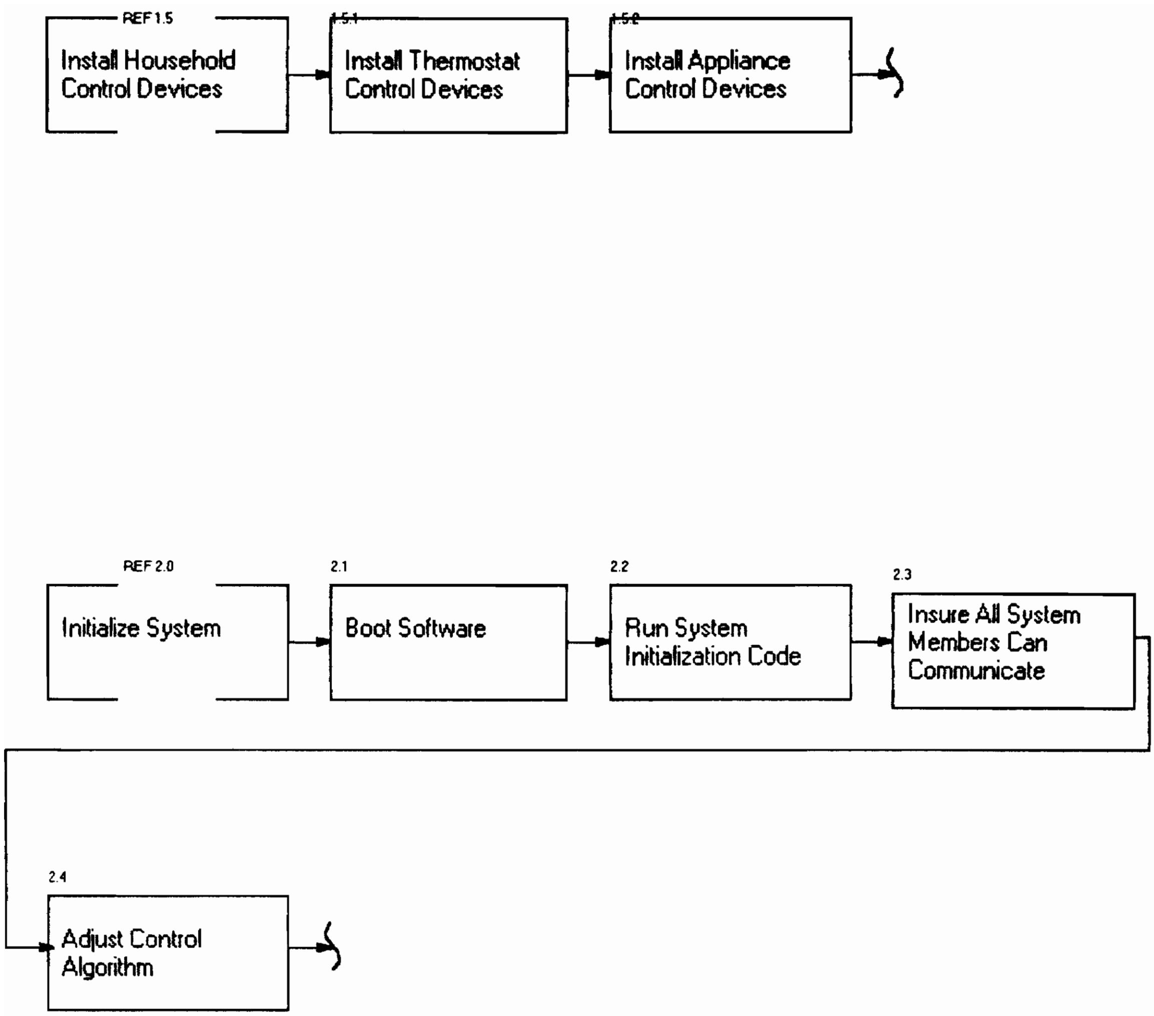


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

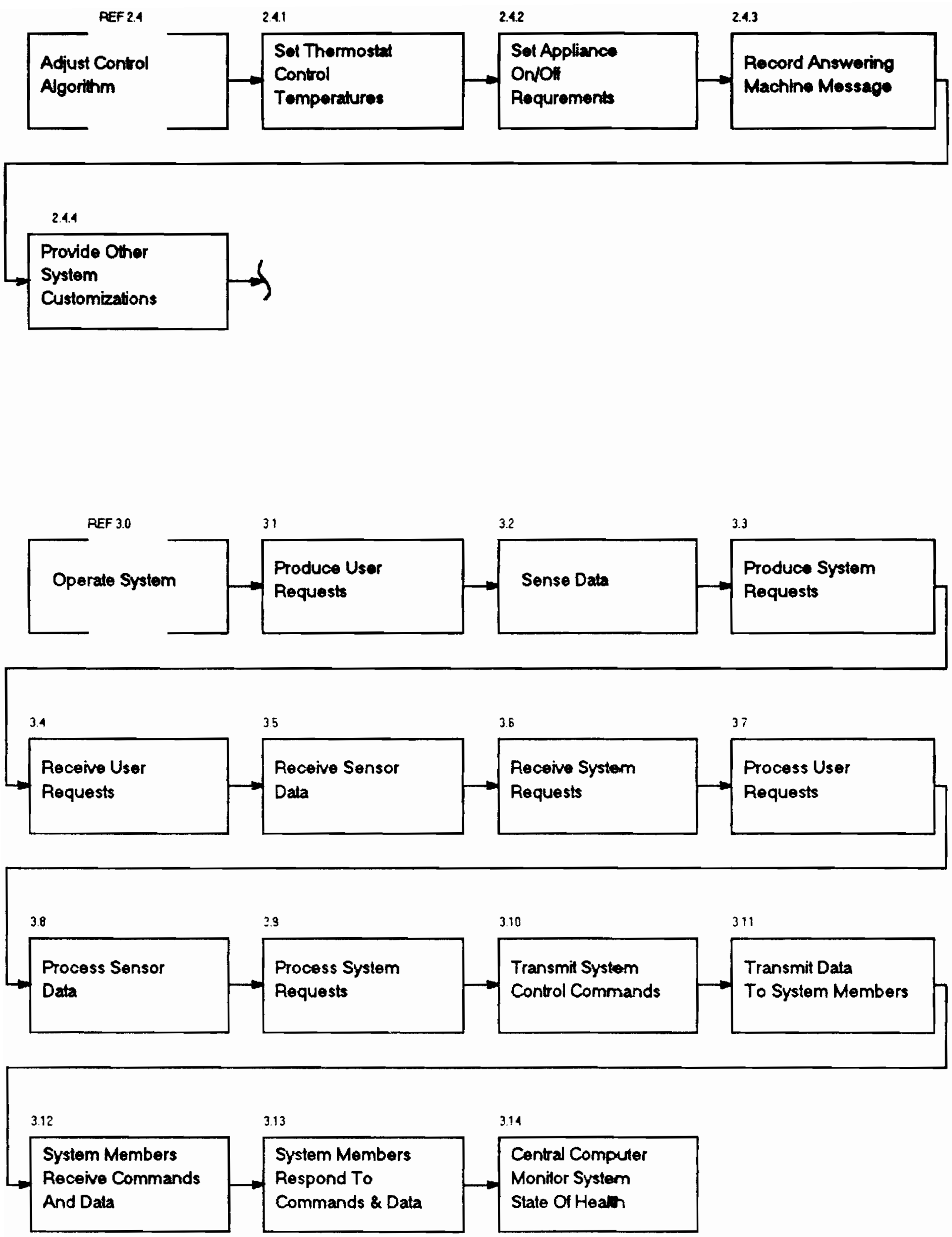


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

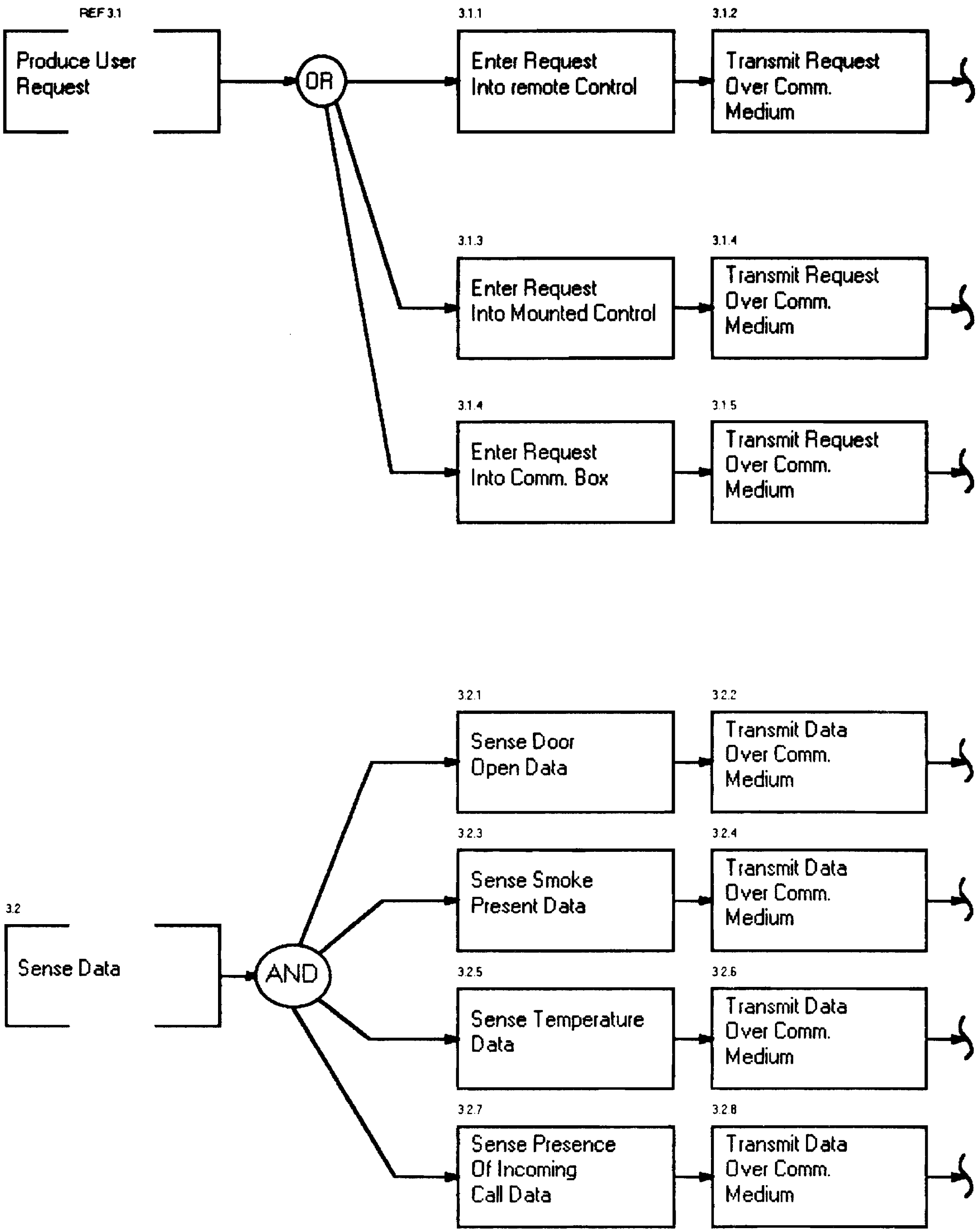
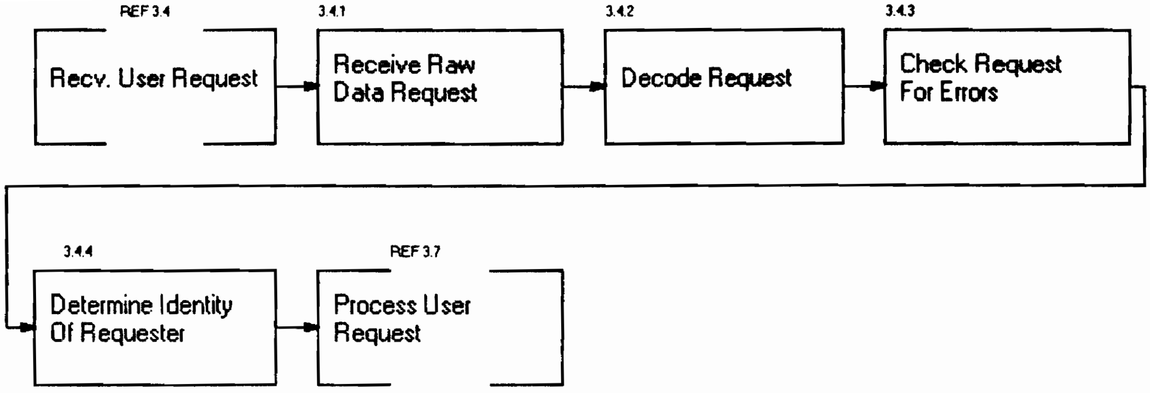


Figure 6.1 Home Automation System Functional Flow Diagram Cont.



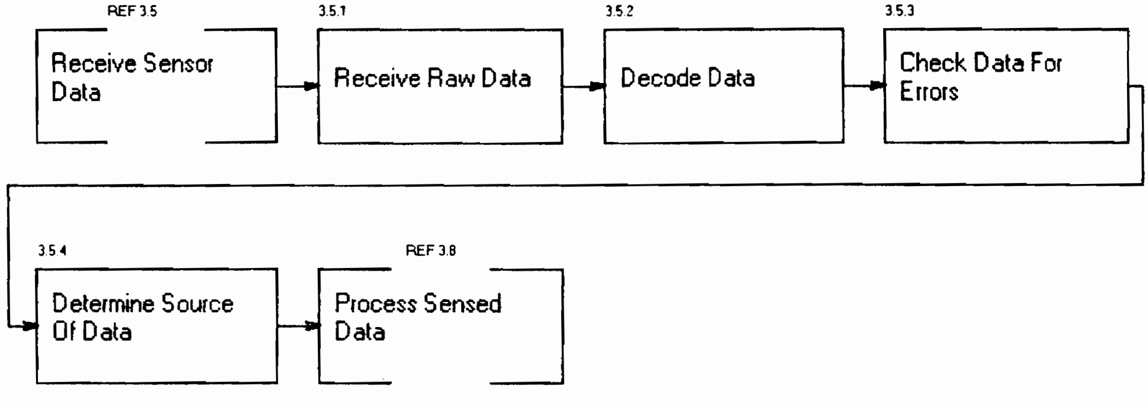
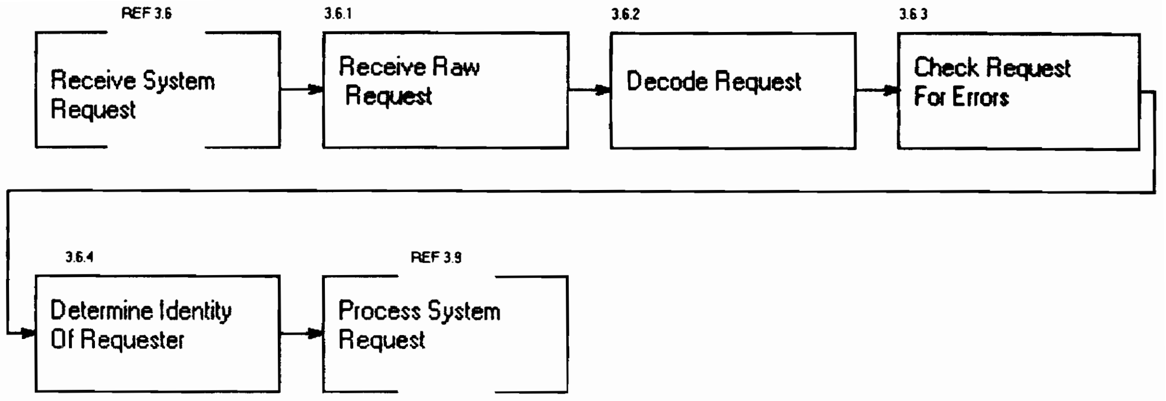


Figure 6.1 Home Automation System Functional Flow Diagram Cont.



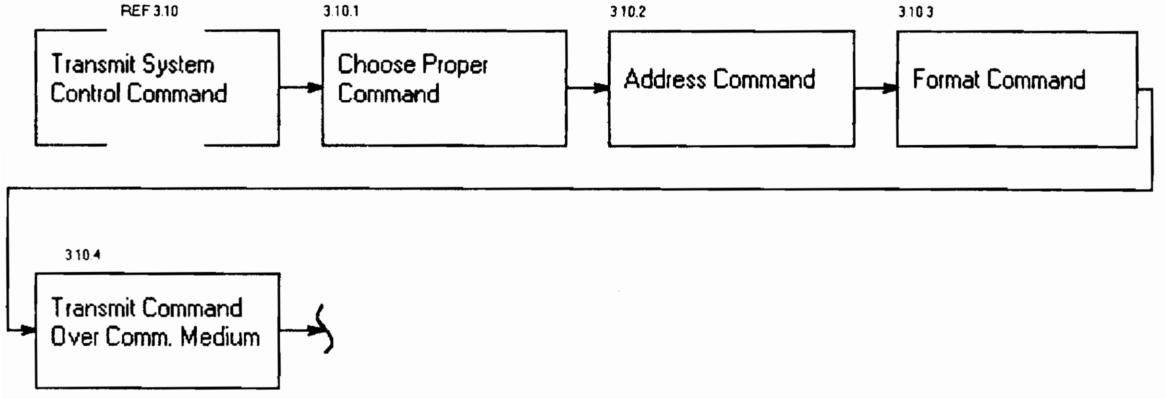


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

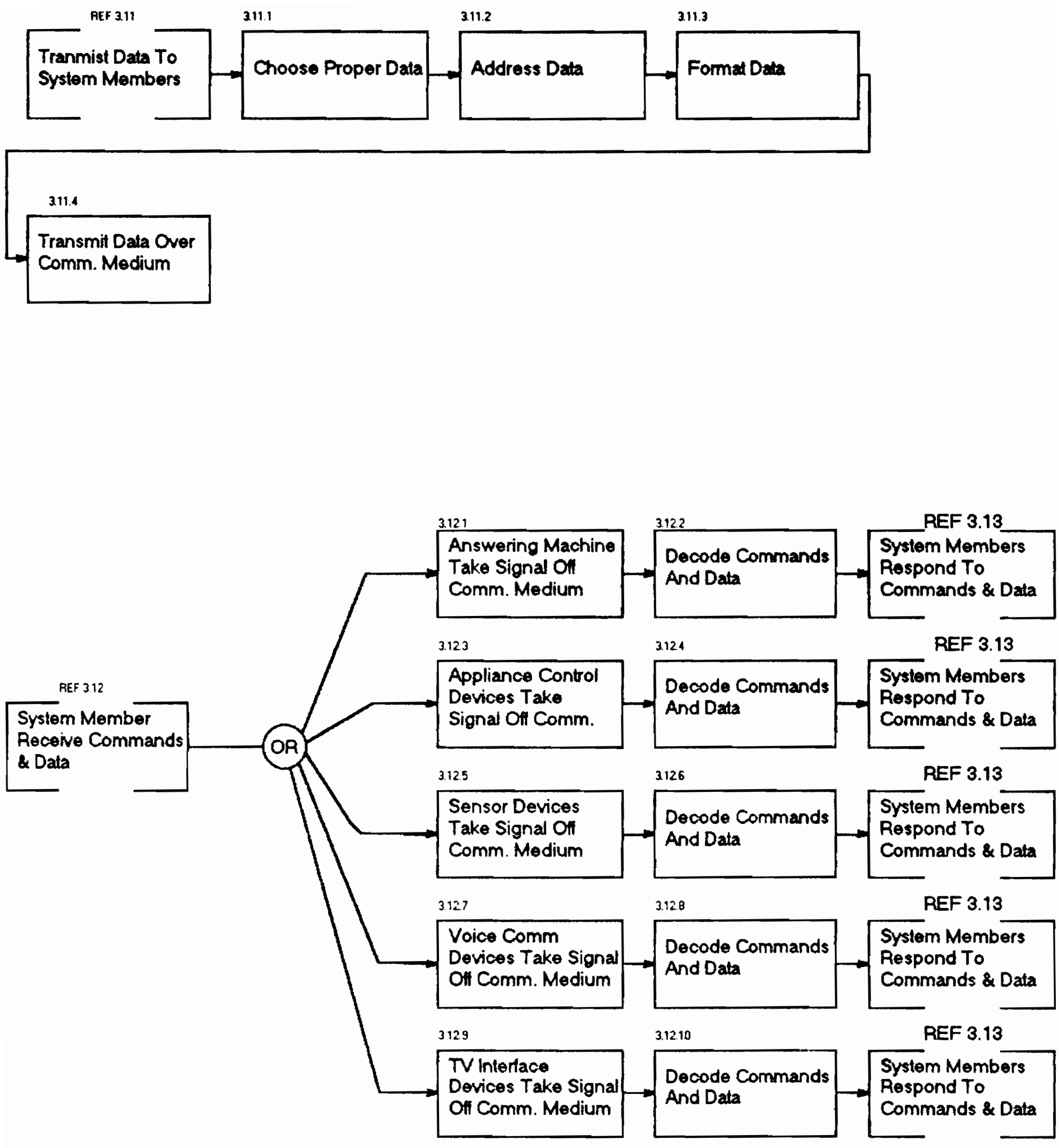


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

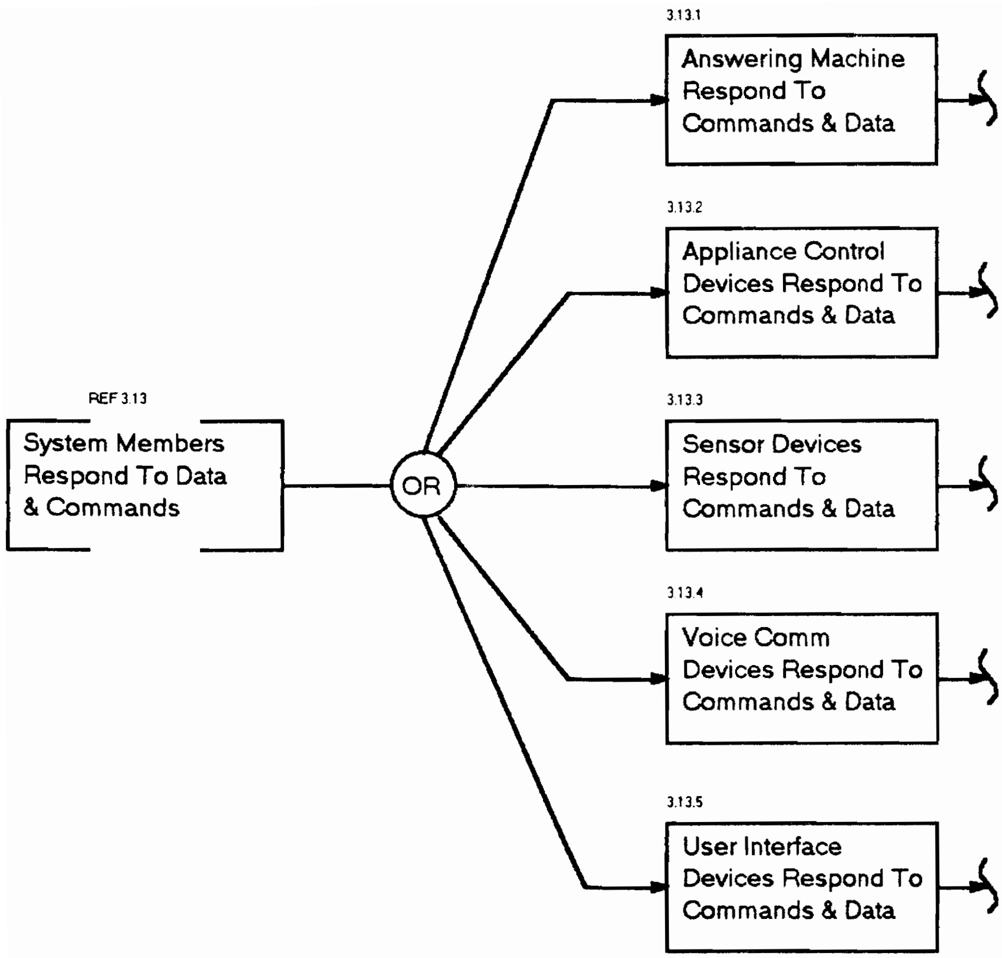


Figure 6.1 Home Automation System Functional Flow Diagram Cont.

Chapter 7: Synthesis And Definition

Home Automation System LAN Design

Introduction

The home automation system LAN design will define how all communications occur over the data link portion of the home automation system LAN. The design will be developed with the goal of best satisfying all of the requirements and specifications set forth previously in this paper. The following is a list of the major requirements guiding the development of the home automation system LAN Protocol:

-The home automation system LAN must provide for highly reliable communications.

-The home automation system LAN must provide quick access between all home automation system devices and the central computer.

-The home automation system LAN must be inexpensive to implement

-The hardware needed for a device to connect to the home automation system LAN must be simple and inexpensive.

-The home automation system LAN must be capable of managing high enough data rates to support all required communications of the system and any reasonable future expansions

Open System Interconnection

The Open System Interconnection (OSI) Architecture will be used as a guide in the development of the home automation system LAN Architecture. The OSI architecture was developed by the International Standards Organization to be used as a guide in the development of LAN architectures. (3,p.45) The OSI Architecture calls for the problem of developing a LAN architecture to be broken into multiple layers. The OSI architecture defines a maximum of seven layers that can be used in the development of any LAN. (2,p.397) Depending on the type of LAN being developed different numbers of layers are required to service the needs of the LAN. The minimum number of OSI layers that can be used are the bottom two layers. (3,p.137) The layers above the bottom two provide the added flexibility that is needed if a LAN is being developed to support numerous types of computer systems running multiple types of software.

The bottom two layers of the OSI Architecture are the Physical Layer, and the Data Link Layer. (3,p.137) These two layers are all that are needed by a system that is relatively restrictive in the types of uses that the LAN is being developed for. The Physical Layer is concerned with the transmission of an unstructured bit stream over the physical communication medium. (3,p.137) The Physical Layer is responsible for such things as signal voltages, and bit duration, and timing. The Data Link Layer is concerned with the structure of the information that is being sent over the LAN. The Data Link Layer is responsible for formatting blocks of data, addressing blocks of data, providing error correction and detection, and for synchronizing transmissions with other members on the LAN. (3,p.137)

Home Automation System LAN Architecture Layering

The home automation system LAN architecture will be composed of the Physical Layer, and the Data Link Layer. Figure 7.1 shows how the home automation system LAN architecture will utilize the two OSI layers.

The Data Link Layer of the home automation system Protocol will be responsible for providing a path between the sending device and a receiving device. Thus the Data Link Layer will be responsible for insuring that data transmitted by a device is properly formatted to interface with the LAN. To accomplish this the second layer will be responsible for such things as identifying when a particular device has access to the LAN, attaching sender and destination addresses to words, and providing error detection coding.

The Data link layer will also be responsible for handling the reception of LAN transmitted data for each device attached to the home automation system LAN. When involved in receiving words from the LAN the Data Link Layer will be responsible for identifying when a frame on the LAN is addressed to the device in question. When a frame addressed to a particular device has been identified it will be the responsibility of the Data Link Layer to provide error detection decoding.

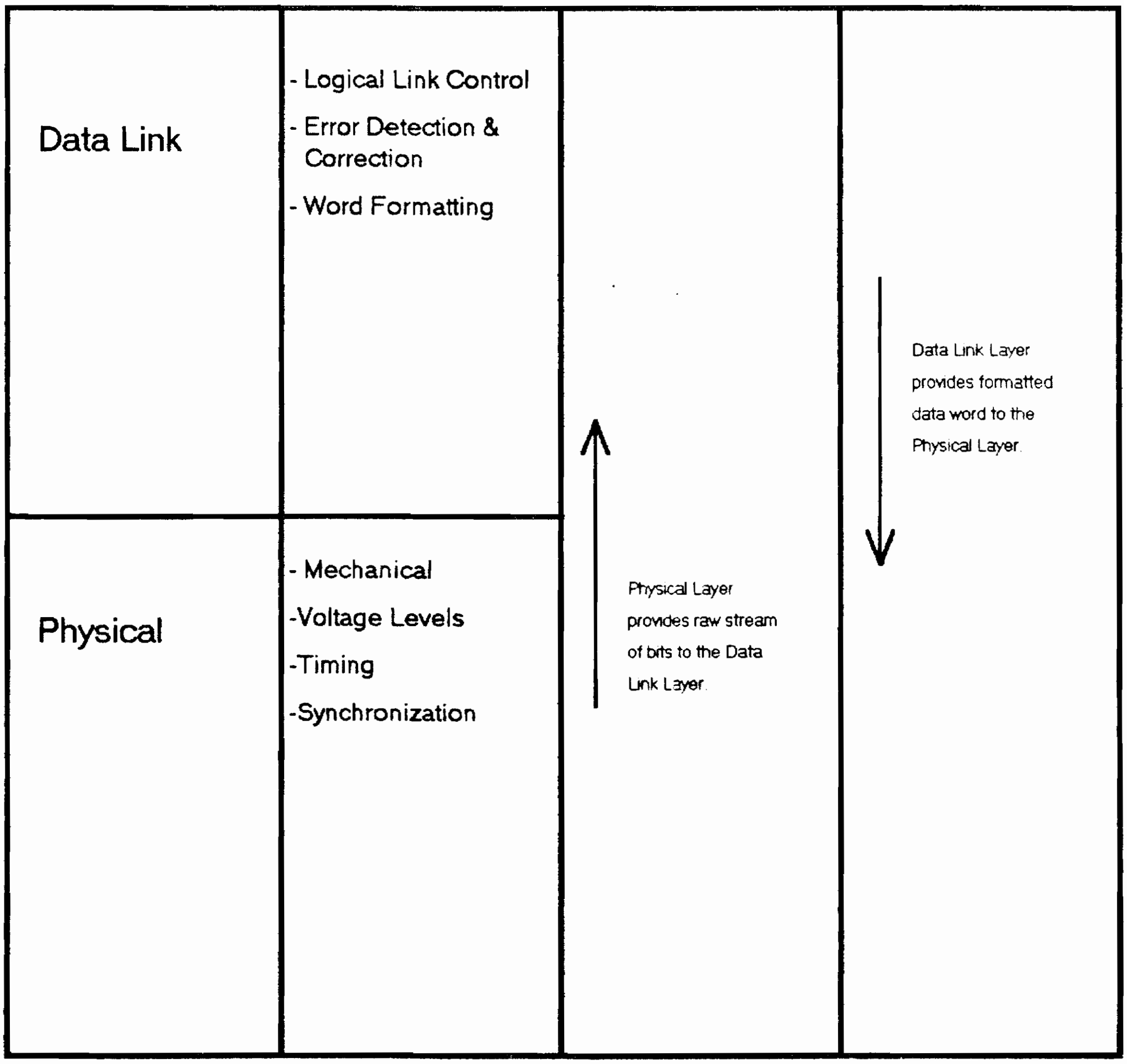


Figure 7.1 Home Automation System Utilization Of OSI Layers

When transmitting the interface between the Data Link Layer and the Physical Layer will be in the form of a frame of bits. The frame of bits will already be completely formatted for transmission on the LAN. The frame presented to the Physical Layer will already have the receiver and sender addresses appended to the frame, and error detection encoding will already have been applied.

When receiving data off the LAN the interface between the Physical Layer and the Data Link Layer will also be in the form of a frame of bits. The Physical Layer will remove each frame of bits off the LAN and pass the raw frame of bits to the Data Link Layer. It will be the responsibility of the Data Link Layer to determine if the received frame of data was addressed to the device under control. If the frame is addressed to the device under control then the data link will provide error detection decoding. The decoded frame of data after having the overhead bits removed will then be passed to the logic elements of the device under control.

In the case of an appliance being controlled the Data Link Layer will pass the processed word to the logic elements in the appliance controller. The appliance controller will then interpret the command words based on the hardwired logic built into its controller hardware. Figure 7.2 demonstrates the progression of a frame starting on the LAN working its way all the way up through the physical and data link layers to the hardware controller.

The design of the Physical Layer will involved the determination of how the home automation system devices will physically interface with the communication medium. This will involve such issues as voltage levels, bandwidth choice, signal timing methods, and communication circuit design. These subjects are beyond the scope of this paper and will be left for the detailed design.

The design of the Data Link Layer of the home automation system LAN architecture involves the development of a LAN protocol, and an error detection scheme. The error detection scheme will be discussed

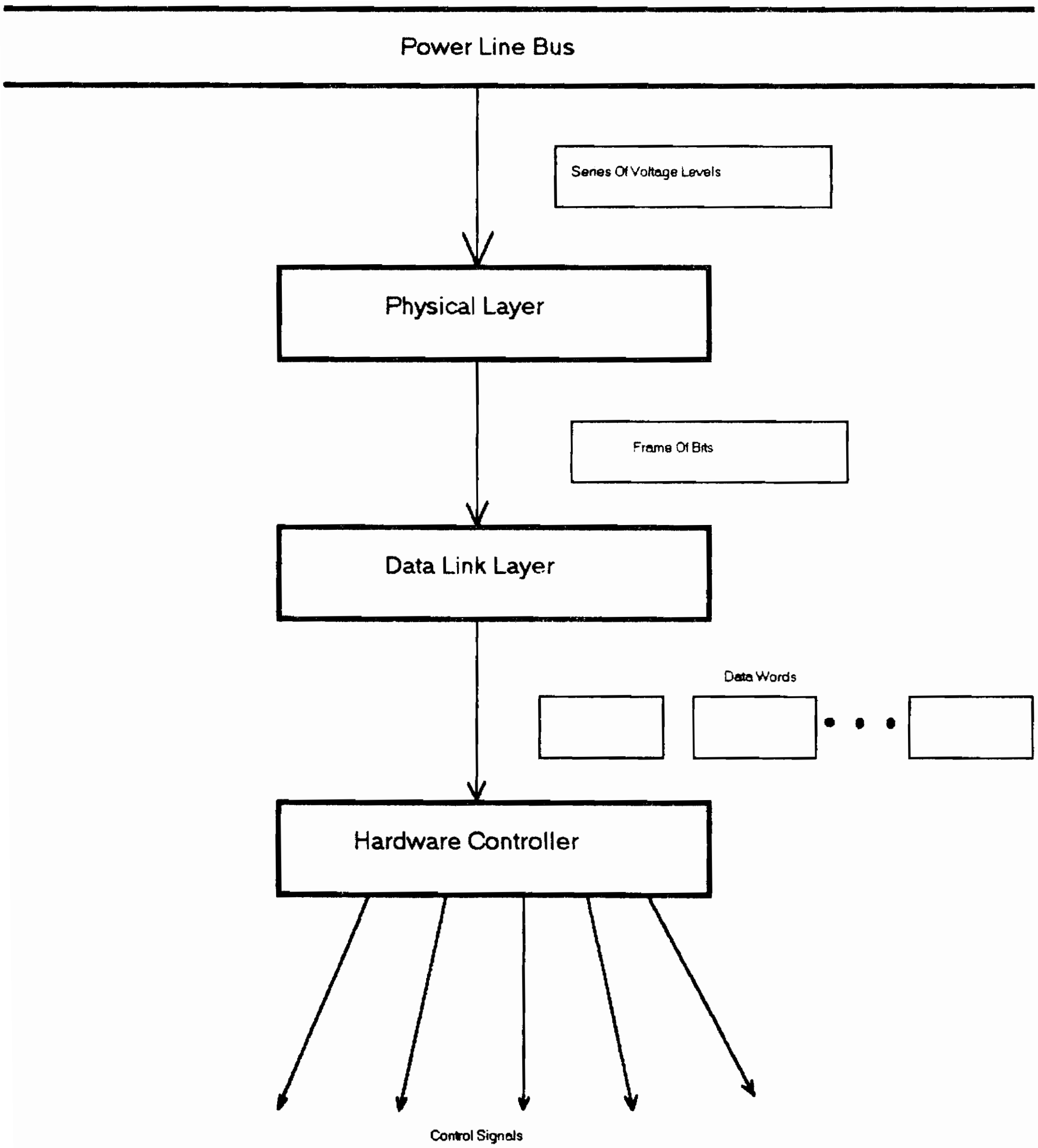


Figure 7.2 Home Automation System LAN Word Progression

in the following section. The following paragraphs deal with the development of a home automation system LAN Protocol.

Protocol Development

The evaluation carried out in the Preliminary System Analysis determined that a LAN protocol based on CSMA/CD would best meet the system operational requirements. The following analysis will develop the home automation LAN protocol using CSMA\CD as a guide.

The most common utilization of a CSMA/CD protocol is the IEEE 802 CSMA/CD. Since IEEE 802 is so well known and well documented it is a easy protocol to work with. Unfortunately the lowest data rate that IEEE 802 is defined for is 1 Mbps. The 1 Mbps data rate is well beyond the 1600 bits per second required by the home automation LAN. Even though the IEEE 802 CSMA/CD cannot be used, due to its data rate incompatibility, many of the features of the CSMA/CD will be incorporated into the home automation LAN protocol. Using the IEEE 802 as the template for the development of the home automation LAN will offer numerous advantages. First using a already proven protocol as a guide will allow the home automation protocol to take advantage of the thought process and experience that went into the development of the IEEE 802 CSMA/CD. Second many engineers are familiar with the IEEE 802 protocol. When an appliance manufacturer wishes to modify one of his products to be compatible with the home automation system there will be a large population of engineers already familiar with the LAN protocol

Data Link Layer

The IEEE 802 further divides the data link layer into two sub-layers. The first sub-layer is called the logical link control layer. The logical link control layer controls the access of multiple devices to the same access point. An access point is a single physical connection to the LAN communication medium. The logical link control layer (LLC) allows multiple communicating entities to physically connect to the LAN at one location. The second sub-layer is known as the medium access control layer (MAC). The job of the MAC layer is to format frames for transmission, unformat frames upon reception, and provide access to the communication medium.

Logical Link Control Sub-Layer

As stated above the job of the LLC layer is to provide access of multiple devices to the same physical access point to the communication medium. The advantage of multiple devices sharing an access point is that multiple devices can logically share the same set of transmission and reception hardware. Figure 7.2 illustrates multiple devices attached to the same point on the communication medium. An example of this type of situation would be an audio system where the CD player, tape deck, and radio receiver all received power from the same power cord. In this type of configuration frames of data could be addressed to any of the audio components. If a frame was destined for the CD player the following set of actions would take place as the frame made its way to the CD player. First the physical layer would receive each of the bits as they were transmitted and pass them to the MAC layer. Note that the physical layer will receive all bits transmitted over the LAN irregardless of what there address is. As the bits are passed from the physical layer to the MAC layer they are assembled into the transmitted frame. When the frame has been assembled the MAC layer identifies its own address and passes the frame minus the MAC address to the LLC layer. The LLC layer examines the LLC address field and identifies that the information bits

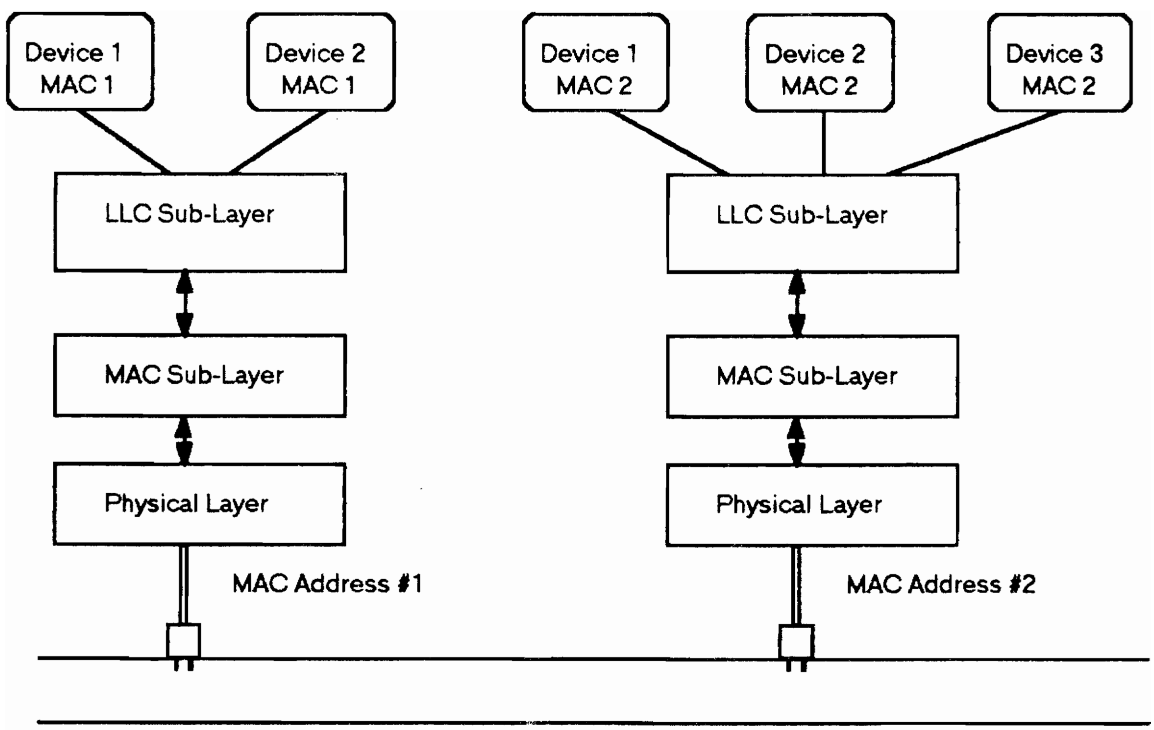


Figure 7.2 MAC/LLC Configuration

in the frame are destined for the CD player. The LLC then passes the information bits to the CD player where its microprocessor can interpret the data and act on it.

LLC Frame Format

As described in the above paragraph the LLC interfaces directly with the device being automated. When a device desires to send information to another device on the LAN it passes the information along with the identity of the receiving device and the priority of the message to the LLC layer. The LLC layer then formats the data into a LLC frame and passes the frame to the MAC layer. Figure 7.3 illustrates the format of the LLC level frames.

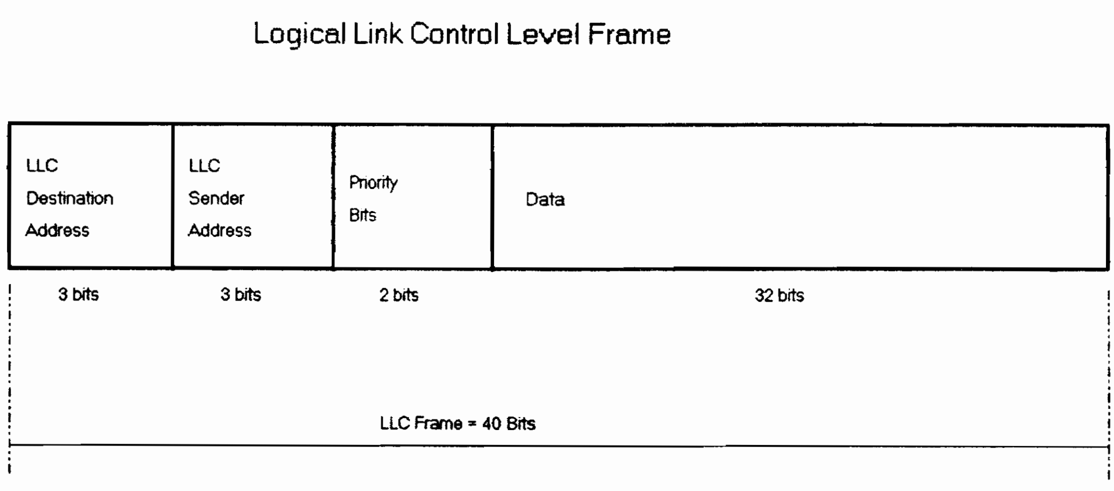


Figure 7.3 LLC Frame Format

The following is an explanation of the fields used to make up the LLC frame

LLC Destination Address (3 bits) - This field is used to tell the receiving LLC layer which device the data passed from the MAC is destined for. The home automation system will allow only five different devises to be attached to a dingle LAN access point. The remaining three addresses (3 bits will allow eight addresses) are reserved for group addressing.

LLC Sending Address (3 bits) - This field is used to tell the receiving LLC layer the identity of the sending address device. This information is used by the LLC when formatting the acknowledgment frame (acknowledgment frames will be discussed in greater detail later).

Priority Bits (2) - The priority bits allow the sending device to identify the priority type of the data being transmitted. The priority bits are not used by the LLC layer and only have meaning to the MAC layer. Priority bits will be discussed more later.

Data (32 bits) - The data bits are produces by the device being automated and consist of the actual information being transmitted.

The acknowledgment frame discussed above also requires a LLC frame format. Figure 7.4 illustrates the LLC acknowledge frame format.

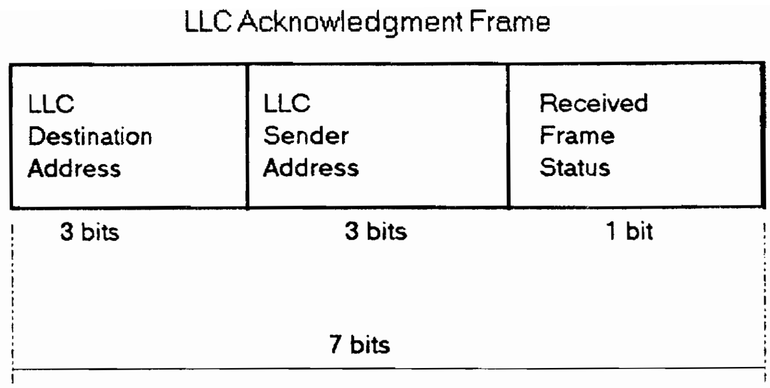


Figure 7.4 Acknowledgment Frame

The acknowledgment frame allows the receiving LLC level to inform the sending LLC level that the frame was successfully received, or that the frame was received in error.

Medium Access Control Sub-Layer

The role of the MAC layer is to format outgoing frames, break down incoming frames, and provide controlled access to the LAN. The MAC layer receives LLC frames form the LLC layer, formats the LLC frame into a form suitable for transmission over the LAN, and then determines when the LAN is available for the transmission of the frame. When the LAN is determined to be open the MAC layer passes the frame of data bit by bit to the physical layer where it is transmitted on the LAN.

Medium Access Control Frame Format

When the MAC layer receives a LLC frame from the LLC layer it is required to put the LLC frame into a format suitable to be transmitted over the home automation communication bus. The MAC layer adds the following fields to the LLC frame in order to prepare it for transmission: a MAC destination address, a MAC sender address, a frame preamble, and a frame check sequence. Figure 7.5 illustrates the format of the MAC frame.

Medium Access Control Frame

Preamble	MAC Destination Address	MAC Receiver Address	LLC Frame (Minus the priority bits)	Frame Pad	Frame Check Sequence
4 bits	8 bits	8 bits	38 bits	2 bits	9 bits

MAC Frame = 72 bits

Figure 7.5 MAC Frame Format

The following is a definition of the fields that the MAC layer adds to a LLC frame when preparing it to be transmitted over the LAN.

Preamble - The preamble allows the MAC layer identify the beginning of a frame of data.

MAC Destination Address - The MAC destination address allows the destination MAC to identify which frames it needs to receive and decode.

MAC Sender Address - The MAC sender address informs the receiving MAC layer who the source of the received frame was.

LLC - The LLC frame is the frame that was produced by the LLC layer. The priority bits are removed since the sending MAC is the only layer concerned with the priority of the frame. The MAC layer uses the priority bits to help it determine when to transmit the frame. The receiving frame does not care what the priority of the message is.

Frame Check Sequence - The frame check sequence allows the receiving MAC to determine if the frame was transmitted and received successfully. The frame check sequence is produces by passing the MAC frame minus the frame preamble through a cyclic encoder. The generation of the frame check sequence is discussed more thoroughly in the next chapter.

Frame Pad Bits - These bits allow the frame to padded in such a way as to avoid confusing part of the encoded frame with the frame preamble.

LAN Addressing

Given the LLC destination address, and the MAC destination address there are numerous type of address combinations that will be acceptable on the home automation LAN. In general the different address types fall into three categories: individual, multicast, and broadcast. Individual is simply a individual MAC or LLC address. Multicast addressing allows multiple devices of a defined type to be addressed at once. An example of this is a multocast message to all lighting devices on the LAN instructing them to turn off. Broadcast addressing allows a single message to be transmitted to every device on the LAN.

Each of the different addressing types have a different effect depending on whether they are issued at the LLC level or the MAC level. A broadcast address at the MAC layer means the message is destined to all MAC layers on the LAN. A broadcast address at the LLC level means the frame is destined for all devices accessing the LAN through the LLC in question. Table 7.1 illustrates all the address combinations that are available on the home automation LAN.

Table 7.1 Address Combinations

MAC Address	LLC Address
Individual	Individual
Individual	Broadcast
Multicast	Broadcast
Broadcast	Broadcast

Address Combination Examples

MAC (individual) LLC (individual) This is the most common address format. This is the type of address that will be used when one device attached to the home automation LAN wishes to pass information to another device attached to the LAN. The individual address at the MAC level causes only the specified MAC to decode the frame and pass the LLC frame up to its LLC layer. The LLC level individual address causes the LLC layer to pass the information bits only to the individual device specified in the LLC address.

MAC (individual) LLC (broadcast) This format of addressing will allow data to be transmitted to all the devices that are attached to the LAN at one access point. This format would be useful if a command need to be sent to turn all devices that were attached at a single access point. If an operator wished to send a command to turn off all components of his audio system. In response to this command a frame would be transmitted over the LAN with a individual/broadcast address format. The MAC layer that controls the access point leading to the audio system would identify the frame of data and decode and deformat the frame. The MAC layer would then send the LLC frame to the LLC layer. The LLC layer would identify the broadcast address and pass the data bits containing a power off command to all the components of the audio system.

MAC (multicast) LLC (broadcast) This format of addressing will allow all devices of a given type to be addressed. This type of addressing would be used if there is a need to send a message to all devices associated with the security system. The multicast address at the MAC layer will cause all MAC layers that control access to the LAN for security devices to decode the frame, unformat the frame, and pass it to the LLC layer. The LLC layer will then identify the broadcast address and pass it to all devices attached at that access point. This will allow a window open sensor and a smoke alarm to share the same access point to the LAN.

MAC (broadcast) LLC (broadcast) - The broadcast broadcast combination will be used when it is necessary to send information to every device on the LAN. The MAC broadcast address will cause all MAC layer to identify the frame, decode it, and pass it to the LLC layer. The LLC broadcast address will cause the LLC layer to pass the information bits to every device attached to that LAN access point. This address format will especially useful for system administration actions. When the system is initialized the controlling computer will send numerous broadcast/broadcast messages out informing all devices on the LAN of the addresses of other devices on the LAN. When a new device is added to the LAN the controlling computer will be responsible to send a broadcast/broadcast message out informing all of the devices of the identity of the new device.

LLC Address MAP

Table 7.2 gives all of the LLC address assignments.

Table 7.2 LLC Address Map

LLC Address	Address Destination
000	Address Of A Device Being Initialized*
001	Broadcast Address
010	Device 1 Address
011	Device 2 Address
100	Device 3 Address
101	Device 4 Address
110	Device 5 Address
111	Device 6 Address

* See LAN initialization

Note that when one device desires to transmit data to another device on the same access point there is no need to gain access to the LAN. Because of this the frame is never sent to the MAC layer. The LLC layer simply sends the frame to the proper device on the same access point.

MAC Address Map

Table 7.3 gives the address assignments for all of the possible MAC addresses.

Table 7.3 MAC Address Map

MAC Address	Address Destination
00000000	Address Of A Device Being Initialized*
00000001	Broadcast Address
00000010 • • • 00110111	Multicast Address 1 • • • Multicast Address 54
00111000	Access Point Address 1
00111001 • • • 11111110	Access Point Address 2 • • • Access Point Address 199
11111111	Access Point Address 200

* See LAN initialization

Note the assignment of multicast addresses to a group of automated devices is under the control of the controlling computer. A group of devices would likely be grouped together into a multicast group as part of the initialization of the system, or under the instruction of the system operator.

Medium Access Control CSMA/CD

Controlling access to the LAN is one of the main responsibilities of the MAC layer. The MAC layer is constantly listening to the LAN to determine if there is data currently being transmitted over the LAN. The MAC layer is able to listen to the LAN with the aid of the physical layer. Whenever the physical layer detects a voltage signal that corresponds to a bit of data it passes the bit up to the MAC layer. The MAC layer is capable of detecting the nine bits sequence that makes up the frame preamble.

When the MAC layer detects a frame on the LAN it informs the LLC layer that it is in the receive mode. If the LLC has a frame that need to be transmitted over the LAN then it informs the MAC. When a MAC layer is informed that there is data available to be transmitted it begins an algorithm that allows it to determine when it should attempt to transmit its data over the LAN. The algorithm involves first testing to determine if there is presently a frame on the LAN. If the LAN is idle, then the MAC immediately transmits its data. If the LAN is busy then the MAC does not transmit its data and continues to monitor the LAN to detect when the end of the frame currently occupying the LAN is. When the MAC detects the end of the frame it waits a calculated period of time and then transmits its data.

The period of time that a MAC waits to transmit its data depends on the priority of the data that it is presently attempting to transmit. The priority of the data is determined by reading the priority bits in the LLC frame. The algorithm that is used by the MAC layer to determine when to transmit after the LAN goes idle is listed below.

1. If the LAN is idle then transmit immediately.

2. If the LAN is busy then wait for the end the end of the frame. When the end of the frame is detected determine when to transmit based on the following rules

> Always wait the period of time required for an acknowledgment frame to be transmitted. After waiting enough time for the acknowledgment frame wait another period of time based on the priority of the LLC frame. If the priority is 00 (00 is the highest) then transmit immediately after the acknowledgment frame if the LAN is still free. If the priority is 01 then wait five bit lengths (3.53 ms) and if the LAN is still idle then transmit. If the priority is 10 then wait ten bit lengths (7.06 ms) and if the LAN is still idle then transmit. If the priority is 11 then wait fifteen bit lengths (10.59 ms) and if the LAN is still idle then transmit.

3. If while transmitting a frame a collision is detected then immediately cease transmission. Transmit a brief jamming signal to insure that all stations know that a collision occurred. After transmitting the jamming signal the MAC layer waits a random period of time and then begins again with step one.

The random period of time that a MAC waits after a collision is necessary to insure that two fames of the same priority don't continue to collide after they first contend with each other. Figure 5.x illustrates the MAC transmission algorithm.

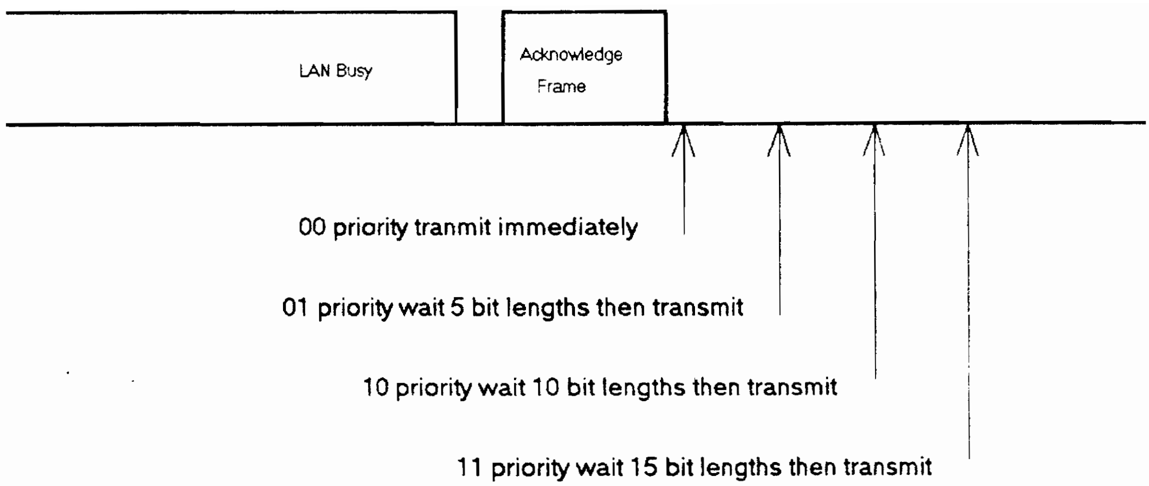


Figure 7.6 Retransmission Algorithm

Error Detection

The MAC layer is responsible for determining if a frame is received error free. The MAC layer can detect an error in two ways. First if a frame is fragmented in some way then the MAC layer knows that there is an error in the frame. An example of this would be a frame with less than 40 bits in the LLC segment of a frame. The second way the MAC layer can detect an error in a frame is by examining the frame check sequence. If the frame check sequence is incorrect then the MAC layer knows that the frame was received in error (see the error detection section for more on the frame check sequence). When a MAC layer receives a frame with no detectable problems the MAC immediately formats an acknowledgment frame and transmits it back to the transmitting station.

System Initialization

System initialization will be required whenever the home automation system is turned on for the first time after installation. When the system is first turned on any devices that are to communicate over the home automation LAN will not have LAN addresses (MAC or LLC). In order to overcome this initial condition all devices compatible with the home automation LAN will be required to have an initialization mode.

When an appliance is place in its initialization mode it will attempt to gain access to the LAN. When it has gained access to the LAN the device will transmit a frame to the controlling computer. The frame transmitted to the central computer will identify itself to the central computer and request a LAN address be assigned to it. Upon receiving the LAN from the device in the initialization mode the controlling computer will format and transmit a response frame to the appliance. The controlling computer frame will contain the new address of the appliance and a command that the appliance terminate its initialization mode. The frame transmitted to the appliance that is in the initialization mode will be addressed with the MAC and LLC initialization address (see LLC and MAC address format). Only a device in the initialization mode will receive a frame with the initialization address.

Since there is only one MAC and one LLC initialization address, only one device can be added to the home automation system at once. If numerous devices need to be added to the system, they will have to be added one at a time. Each device to be added will be placed in the initialization mode, one at a time until all devices have been added to the system.

After a system has been initialized, the initialization mode will only be used when a new device is added to the system. Should the power to the home automation system be lost, there will be no need to re-initialize the system. All devices compatible with the home automation communication protocol will be required to have one eight bit register of non-volatile memory. Should power be removed from the appliance, the non-volatile memory will save the address of the device. The controlling computer will store the addresses of all valid devices active in the home automation system on its hard drive. Should power be removed from the controlling computer, the addresses of all the devices will still be available on disk.. When power is restored to the controlling computer it will re-boot the home automation software and load the addresses of the devices off of disk..

Types Of Communication

There will be three types of communication available on the home automation system LAN. The first will be a signal sent from the central computer to one of the devices being controlled by the home automation system. An example of this signal type will be the central computer sending a signal on the LAN instructing a television to turn on. The second signal type will be a signal sent from one of the devices on the LAN to the central computer. An example of this signal type will be a smoke alarm informing the central computer that smoke has been detected. The third type of signal will be a signal between two devices that are on the home automation system LAN. An example of this signal type would be a clothes washing machine notifying a dish washing machine that it is finished using the hot water. Figure 7.8 illustrates the three types of the signals that may exist on the home automation system LAN.

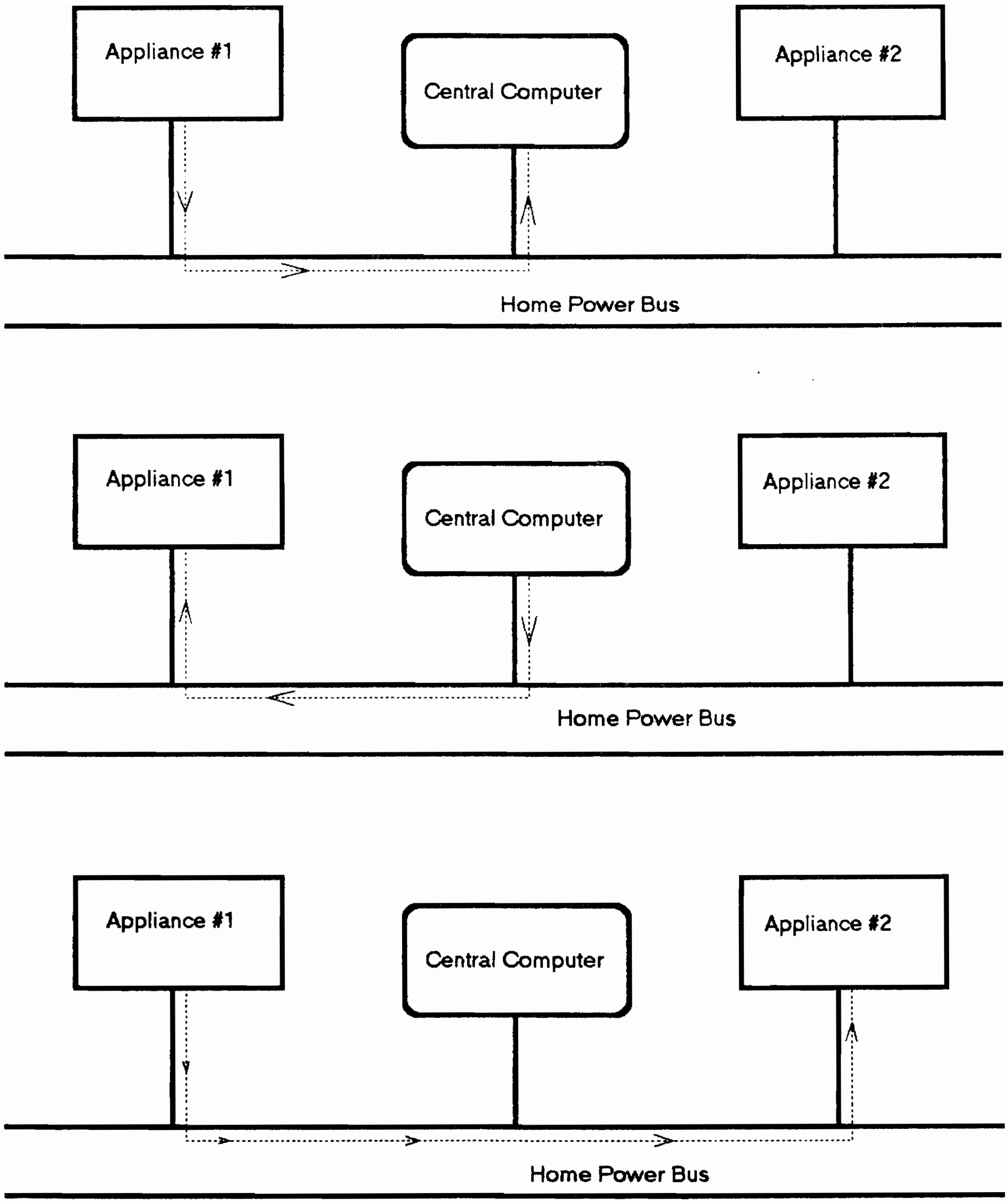


Figure 7.7 home automation system LAN Signal Types

Error Detection Preliminary Design

Introduction

The Allocation of Requirements section places the requirement on the home automation system LAN that it be able to perform communications over the LAN with a high degree of reliability. In order to insure that the home automation system LAN meets this requirement a error detection scheme must be employed. The error detection scheme should decrease the chance that a word is interpreted incorrectly by a device receiving information on the LAN. The error detection scheme must be effective enough to eliminate a large percentage of the erroneous information that will be added to each frame due to noise on the home automation system LAN.

Error Detection Review

Figure 7.8 illustrates in general how most error detection codes work. Set 'A' is the set consisting of all possible message words. That is any word that is transmitted will be a member of set 'A'. Set 'B' is a set that has many more members than set 'A'. The coding process seeks to map every element in set 'A' to a particular member in set 'B'. (12,p.271) Every member of set 'A' has a one to one correspondence with a single member of set 'B'. The members of set 'B' that through the coding process have a one to one correspondence with members of set 'A' define subset 'C'.

Every member of 'A' is 'k' bits long. The number of members of set 'A' is equal to two raised to the kth power. Every possible word that is 'k' bits long is a member of set 'A'. Every member of set 'B' is n bits long. The number of members in set 'B' is equal to two raised to the nth power. Every possible word that is 'n' bits long is a member of set 'B'. Since 'C' is a subset of 'B' all of the members of 'C' will also be 'n' bits long. But since every member of set 'C' has a one to one correspondence with a member of set 'A', the number of members of set 'C' is equal to two raised to the kth power.

When the transmitter passes a message, from set 'A', into the encoder a 'n' bit long codeword that is a member of set 'C' is produced. Since the receiving station will always receive a word that is n bits long, the received word will always be a member of 'B'. In order for a received word to be deemed error free it must also be a member of 'C'. Thus when errors that occur during transmission cause a signal that was once in 'C' to no longer belong to 'C' the receiving station knows that the word was received in error.

The possibility exist that the error in the frame will cause the transmitted member of set 'C' to be transformed into a different member of set 'C'. In this case there is know for the error detection scheme to determine that the received member of set 'C' was not the originally transmitted member of set 'C'. When this scenario is encountered the receiving system will incorrectly interpret the reserved frame. The goal of an error detection scheme is to be designed well enough to lower the percentage of misinterpreted words below the reliability requirements placed on the communication system.

Based on the above discussion it is clear that the error detection codes have three main responsibilities. First they must be able to take a set and divide it into two partitioned areas ('B' and 'C'). The first area will consist of all the possibly transmitted words ('C'), and the second will correspond to all the words in the set that are not possibly transmitted words ('B)'. The more different each member of set 'C' is from all the other members of set 'C', the more successful the error detection code will be. The second responsibility of the error detection is to map each member of the message words ('A') into the subset of possibly received words ('C'). The third responsibility of the error detection is to provide a way to detect when the received word is not a member of set 'C'.

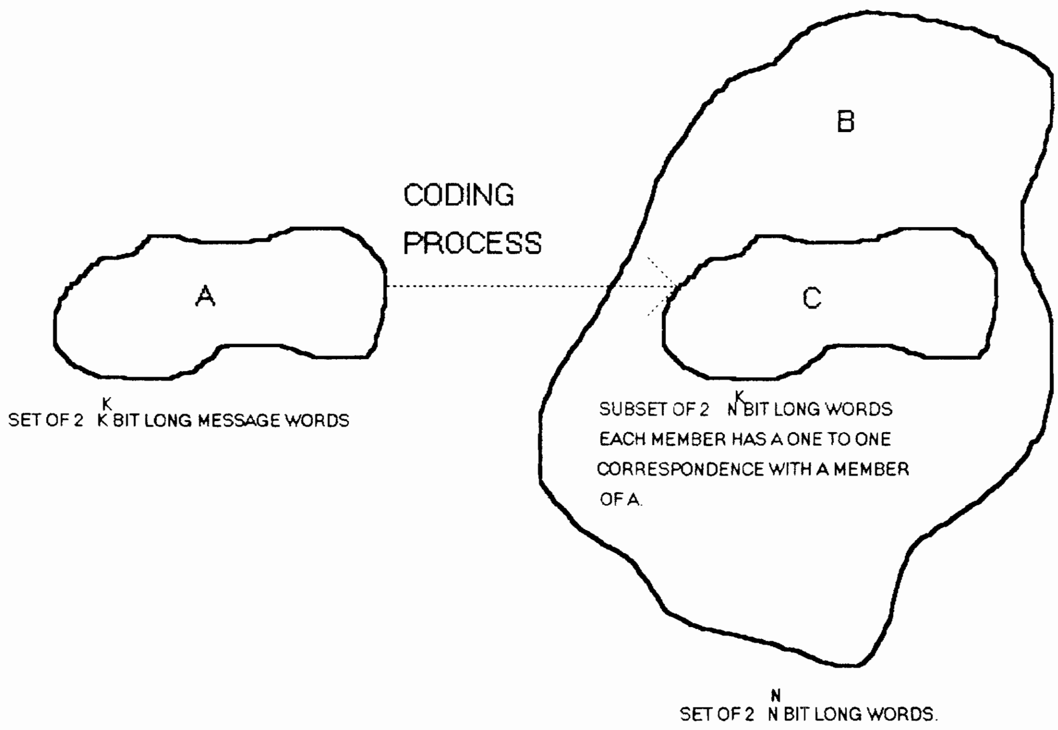


Figure 7.8 Example Of Coding

Definition Of Terms

The following terms will be used in the discussion of the error detection code design:

-Message Word Refers to a system data word before it has been encoded (e.g. a member of set 'A').

-Code Word Refers to a message word after it has been encoded (e.g. a member of set 'C').

-Frame Check Sequence Refer to the bits that are added to a message word while generating a code word (e.g. the bits that cause a message word to change from a 'K' bit long member of set 'A' to a 'N' bit long member of set 'C').

-Information Bits Refer to the bits that make up a message word (e.g. the 'K' bits of a message word).

Burst Errors -VS- Random Errors

Before the decision can be made as to which error detection scheme is best suited to be used on the home automation system LAN, a determination must be made as to the most likely characteristic of errors that will occur on the electrical bus. Namely will the errors most likely occur as random errors or as burst errors. Random errors are the name given to errors that occur in an individual bit with no affect on whether the next bit will have an error. (4,p.11) Thus when any bit in a word is in error the next bit in the sequence is no more likely to be received in error. Burst errors are errors that are more likely to affect multiple bits in a word. (4,p.11) When a burst error occurs in a bit the bits around it are more likely to also have an error. Burst errors are characterized by a system that may go a long period with no interference in the communication medium but occasionally have interference that will effect a series of bits.

Some error detection codes are better at detecting random errors and some error detection codes are better at detecting burst errors. Thus it is fairly important that the home automation system communication medium be identified as either being more prone to random errors or to burst errors.

Due to the power spikes that occur on a home electrical buses when large appliances turn on or off it is most likely that a large percentage of errors occurring on the home automation system LAN will be do to burst errors. When a power spike is experienced on the power bus a certain percentage of the power in the spike may exist in the same frequency range as the data on the home automation system LAN. Thus a power spike may wipe out a group of bits that are being transmitted at the same instant as the power spike. Based on this it seems likely that the home automation system LAN will be likely to have a large number of burst errors.

While it is deemed very important that the home automation system LAN decoding circuitry be able detect and correct burst errors it is also important that the home automation system error detection retain the capability to detect errors occurring in single bit locations (random errors).

Code Type

The IEEE 802 CSMA/CD protocol uses a cyclic encoding method known as a cyclic redundancy check to produce its frame check sequence. Cyclic codes are excellent codes for use in local area networks due to their powerful error detecting capabilities, and their ease in implementation. The IEEE 802 protocol call for a thirty-two overhead bits to be used in the frame check sequence. (2, p106) Due to the much smaller size frame that will be used in the home automation system, thirty-two bits would be over burdensome amount of error detection capability. Thus the IEEE 802 error checking scheme will need to be reduced in order to be used in the home automation LAN protocol. In order to produce a cyclic redundancy check for the home automation system, the same procedure that was used in the generation of the 802 cyclic redundancy check will be applied to the 72 bits in the home automation frame.

Cyclic Codes

When a transmitter is using a cyclic redundancy check, it appends a "n" bit word to the back of the "k" bit frame it is about to transmit. The "n" bit word is produced based on the value of the "k" bit frame in such a way when the "n + k" combination is divided by a predetermined number the remainder will be zero. (2, p108) When the receiver receives the "n+k" bit combination it divides the sequence by the same predetermined number. If the remainder is zero, then the "n+k" bit sequence is judged to have been transmitted and received correctly. If the remainder is anything other than zero then the receiver identifies the "n+k" as having at least on bit error.

The difficulty with cyclic redundancy checks is determining the predetermined number that will work well with a given number of bits for "k" and "n".

Determination Of Code

The analysis leading to the code values is carried out more easily if sequences of bits are represented as a polynomial using a dummy variable "x" to act as a place holder for the bits. The sequence of bits 101101 is represented $1+x^2+x^3+x^5$. In order to produce the predetermined value that will be used by a transmitter to encode data and a receiver to decode data, the minimum distance required of the code must be determined. The System Operational requirement called for a error detection capable of detecting three bit errors. A cyclic code that can detect three bit errors will have the following minimum distance: (4, p142)

Minimum Distance = md

d = The number of detectabel bit errors = 3

$$md \geq d + 1$$

$$md \geq 4$$

The home automation cyclic code will be developed in an extension field in GF(64). In order to define an extension field that can be used to produce a code with a minimum distance of four the minimal polynomials that are used to generate the extension fields must be examined. A cyclic code will be generated with a minimum distance if the minimal polynomials used to generate the extension fields has three roots with consecutive powers. (4, p130) The first thee minimal polynomials and their conjugates are listed below

Galois Field Sixty-Four

Minimal Polynomials & Their Roots

Minimal	Polynomial	Roots
0	$1 + x$	α^0
1	$1 + x + x^6$	$\alpha^1,\ \alpha^2,\ \alpha^4,\ \alpha^8 \ldots$
3	$1 + x + x^2 + x^4 + x^6$	$\alpha^3,\ \alpha^6,\ \alpha^{12},\ \alpha^{24} \ldots$

The circled roots show that the first two minimals have roots with three consecutive powers. Thus the extension field generated by the product of the first two minimals will define a cyclic code with a minmal distance of four. The following analysis illustrated the development of the generator polynomial that will be used to encode and decode the home automation fields

$$
\begin{aligned}
g(x) &= (1 + x)(1 + x + x) \\
&= 1 + x + x + x^2 + x^6 + x^7 \\
&= 1 + x^2 + x^6 + x^7
\end{aligned}
$$

The generator polynomial when written in binary form is the predetermined value that will be used to both encode and decode the home automation data.

Code Capabilities

The code that will be produced with the generator polynomial produced above is guaranteed to detect at least three bit errors per frame but it also has other error detection capabilities which are enumerated in the table below.

Table 7.4 Cyclic Redundancy Check Capabilities

Type of Error	Probability Of Detecting
Single Bit Error	100%
Two Bits In Error	100%
Three Bits In Error	100%
Any Odd Number Of Bit Errors	100%
Any Burst Error Less Than Seven Bits	100%
Any Burst Error Of Seven Bits	98.4%
Any Burst Error Greater Than Seven Bits	99.2%

Implementation Of Encoder

The implementation of a cyclic encoder is fairly simple. The only required hardware is a shift register, a few exclusive-or gates, and a 2x1 multiplexer. Figure 7.9 illustrates the encoder that will be needed by every device that is required to transmit data on the home automation LAN.

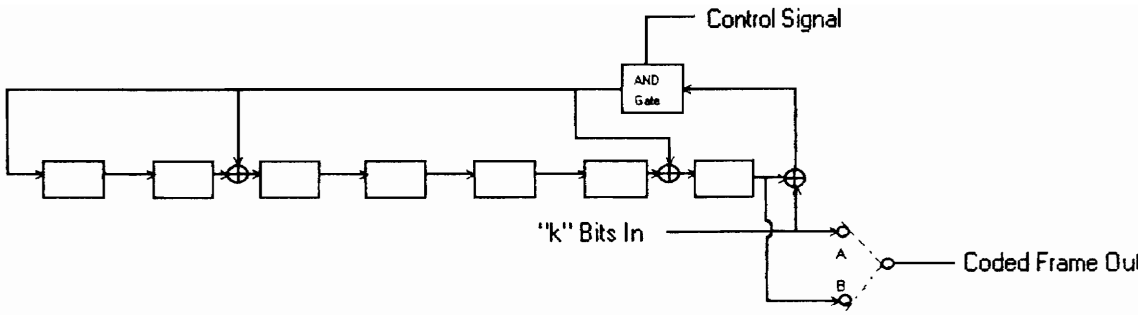


Figure 7.9 Home Automation System Error Detection Encoder

In Order to use the circuit in Figure 7.9 to produce the encoded sixty-three bit home automation frame, the initial "k" encoded bits are first shifted in with the switch set too position "A". The "k" bits are shifted in "k" times. As the initial shifts are occurring, they are both being shifted out to form the first part of the coded frame and being shifted into the shift register to produce the error check sequence. After the "k" shifts, the seven register will contain the error check sequence. At that point the switch is thrown into the "B" position and the seven error check bits are shifted out behind the initial fifty-six bits. While the error check bits are shifted out, the same control signal the causes the switch to throw also takes advantage of the AND gate to disable the feedback path.

Implementation Of Decoder

The implementation of the cyclic decoder is very similar to the cyclic encoder. All devices that are receive information off of the home automation LAN will be required to have a cyclic code decoder. Figure 7.10 represents the circuit that will be required to decode the home automation cyclic code.

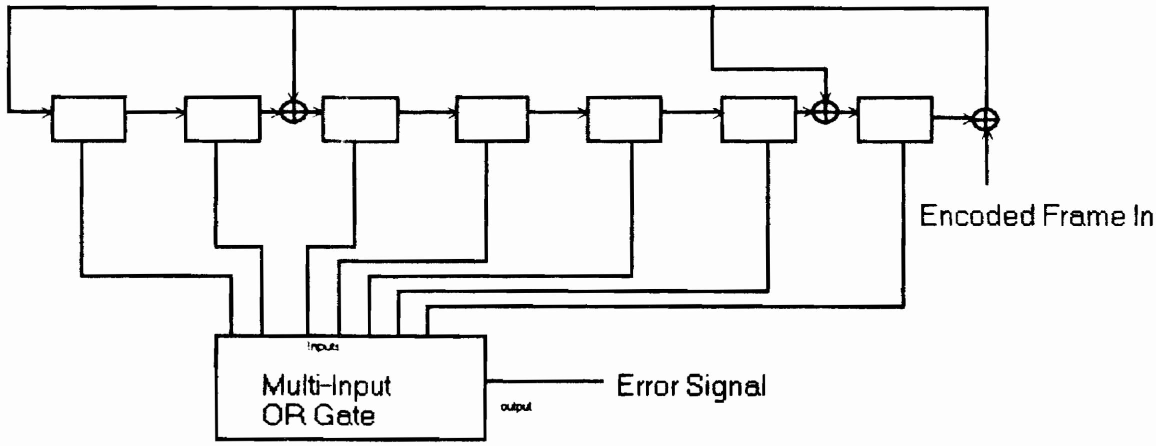


Figure 7.10 Home Automation System Error Detection Decoder

The encoder will decode the received encoded frame when it is shifted into the decoder. After the sixty-three shifts that are required to shift the frame minus the preamble bits into the decoder, the or gate is used to examine the bits stored in the seven registers. If there is anything other than zeros in the registers then the OR gate will produce a "1" which will indicate that the frame was received with an error.

Chapter 8: Conclusion

This report was undertaken to develop a home communication protocol. The objective of the home communication protocol was to provide a mechanism for appliances in the home to communicate with each other and a controlling computer. The preliminary design for the communication protocol presented in this paper is the first step in the development of the final design which will provide a protocol that will allow the manufacturers of appliances and consumer electronics devices to develop their products such that they are compatible with the home communication protocol.

The preliminary design presented in this paper was developed by following the Systems Engineering Process. The paper began with a needs analysis. The result of the needs analysis was a clear indication that a real need exist for a system that would allow certain appliances in the home to be automated. The next step taken in the engineering process was to determine what possible technical approaches could be used to develop a system capable of handling the need defined in the needs analysis.

After the most suitable methods for producing a home communication protocol were listed, the system operational requirement for such a system were listed. The system operational requirements which were based in large part on the needs analysis are the requirements that the home communication protocol will have to live up to in order to fulfill the defined need. The operational requirements are used as a guide in the development of the rest of the design.

The system operational requirements were then used when the evaluation criteria was developed to determine what the best communication protocol configuration would be. Each of the design approaches recommended earlier in the paper were evaluated based on the system operational requirements. The design approach in each category of the system that best matched the criteria was chosen as the initial design approach. The sum of all the chosen design components is the initial conceptual design.

The second part of the paper deals with taking the conceptual design and developing it into the protocol presented as the preliminary protocol design. The preliminary design includes a description of the development of the LAN protocol and the error detection scheme that will be required to ensure reliable communication over the LAN.

Although the Systems Engineering Process was used in the development of the protocol, certain important portions of the process were not addressed. These segments of the Systems Engineering Pocess were not addressed in the hopes that a significant portions of the Systems Engineering Process could be illustrated without expanding the scope of the report beyond reasonable bounds. The two most important segments of the Systems Engineering process that were not covered are the maintenance concept for the system and an analysis of the system life cycle cost.

The next required stage in the development of the home communication protocol is the detailed design. The detailed design will be responsible for taking the preliminary design and its requirements and determining a method of implementing them.

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Appendix A: Home Automation Prototype

The author of this report designed and built a prototype to test the concept of transmitting control signals between devices over a home power line. The prototype consisted of two microprocessor devices. Each microprocessor based device used an Inter 8085 microprocessor as its CPU. Both devices were very similar in design however one of the devices was designed to transmit data over the power line and the other device was designed to receive data transmitted over the power line.

The device that was designed to transmit data over the power line was built to allow an operator to throw switches on the device that would cause a control signal to be transmitted over the power line. The device designed to receive data off of the power line was built such that home appliances could be plugged into it power sockets on the device. The receiving device was capable of either applying or removing power to the power sockets attached to it based on the control signals generated by throwing switches on the transmitting device.

Each device (both the transmit and receive) were equipped with four kilobytes of ROM and eight kilobytes of RAM. The ROM stored the operating code that instructed the 8085 microprocessor how to communicate over the home power line. The operating code included instructions for the microprocessor as to how to interpret the various switches that could be thrown by the operator. The receiving devices operating code instructed the 8085 as to how it could respond to the various control signals that could be transmitted to it by the transmitting device.

The hardware that allowed each device to interface with the home power line consisted of a UART, a modulator (for the transmitter), an amplifier, a demodulator, and a band-pass filter. When the transmitting device was required to transmit data over the power line it would transfer the binary data in parallel to the UART. The responsibility of the transmitting UART was to convert the parallel data into a serial bit stream, provide synchronization with the receiving UART, add a parity bit to the transmitted data, and append parity and end frame bits to the data.

The data that was to be transmitted was then clocked out of the UART in a serial format at a bit rate of 300 bits per second. The data leaving the UART was passed through an analog amplifier circuit which converted the signal into a serial stream of none return to zero pulses with a ten volt peak-to-peak voltage. After being amplified, the bit stream was passed through a frequency shift keying modulator which placed the serial bit stream on a 1 KHz carrier. After the bit stream was modulated, the signal was passed through a band pass filter and onto the power line. The band-pass filter was constructed out of components capable of withstanding the high voltage signals on the home power line. The band-pass filter served to protect the rest of the device from the 60Hz, 110 VRMS signal.

The receiving device filtered the signal off of the power line with a similar bandpass signal to the one used in the transmitting device. The filtered signal was then passed through an envelope detector which served to demodulate the frequency-shift-key modulated signal. The demodulated signal was then passed through an amplifier before being passed to the UART. The receiving UART then assembled the serial bit stream back into the transmitted word. The UART also checked the parity bit of the received frame. After the UART reassembled the serial bit stream it would set a control signal high which informed the 8085 that there was a data word available for it. When ready, the 8085 provided a control signal which caused the UART to pass in parallel the received data to the 8085. Once inside the 8085, the microprocessor issued control signal to the controlled sockets based on the instructions in the received data. The sockets attached to the receiving microprocessor were such that they allowed a five volt TTL signal to open and close a switch which controlled the path of the high voltage home power signal to the appliances attached to the receiving device.