A BROADBAND NETWORK STATUS MONITORING SYSTEM USING MULTIPLE PROCESSORS

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MANITOBA TELEPHONE SYSTEM

ABSTRACT

A hardware and software system capable of monitoring up to ten Cable TV networks is discussed. The use of multiple processors in combination with a real time multi-tasking operating system allows rapid detection and analysis of network faults. In addition to the reporting of catastrophic failures, amplifier alarm and analog data converted to digital are obtained and placed into a memory resident database during normal polling. Monitoring a Cable TV trunk presents a unique challenge due to the fact that the facility itself is used to carry monitoring communication. During partial network failures, reliable monitoring communication may not be possible. This system provides failsafe measures to minimize uncertainty during failure conditions. A communication problem is not allowed to affect all stations in the system because of the separate hardware ports and software tasks that accomodate each trunk.

INTRODUCTION

Manitoba Telephone System (MTS) has four Intercity Broadband Network (ICBN) trunks in place which facilitate the transmission of CATV, broadcast, and teleconference services between some of the major centres within Manitoba. Service areas are widely separated, both in terms of travelling distance and the number of active components. Status monitoring has therefore been essential in order to achieve acceptable availability.

The addressing capability of the original status monitoring system installed by Manitoba Telephone System was limited to 255 stations. The ICBN expanded and the small expansion capability was quickly lost. This was one of the limitations which prompted MTS to consider up-grading the central computer system while utilizing the existing transponders which were supplied with the Century III amplifier stations. Other limitations were that the system was single tasking, could only support one user terminal, and did not provide flexible alarm point usage.

Manitoba Telephone System issued a specification for a new status monitoring computer system and interface. The basic concept of the new system was to provide separate interfaces to each trunk (up to 10) and use these to communicate with a master computer. Quotations were received for two general design strategies. One was that the trunk interfaces would connect to a minicomputer via RS232C interfaces. The second design was that of a micro computer system that avoided the serial interface by including all interfaces in one custom system. This design was proposed by a Canadian computer supplier and accepted by MTS because of the inherent cost savings.

The system described in this paper is now operational with the exception of some software enhancements. The focus of this paper will be to identify and describe the key features of this system, especially with respect to large capacity operation, while avoiding a complete feature by feature description.

SYSTEM OVERVIEW

Maintainability of CATV trunks can be greatly enhanced by providing a central status monitor. A reasonable framework of requirements for a status monitor can be developed from the following functions:

1) Minimize length of time required to locate the cause of catastrophic failures.

2) Continuously monitor key performance indicators such as pilot levels.

3) Provide early warning of possible failures so that corrective action can be taken.

The ability of the system to locate the extent of catastrophic failures is vitally important, but ironically is usually the least frequently used feature of a status monitoring system. A key feature of the MTS broadband network status monitoring system is its ability to pre-process the alarm conditions that result when there is an outage. The desired output to the user specifies a synopsis in compressed form which will indicate possible failure causes whenever practical.

Communication to and from the amplifier stations is facilitated by data modulation of a forward trunk carrier and a keyed reverse trunk carrier. The data format for this system is a 300 bit/second Kansas City FSK standard which equates 1200 Hz to a binary 0 and 2400 Hz to a binary 1. The information sent from the computer to the transponders consists of an address byte, switch control information bits, and an 8 bit cyclic redundancy check byte. The format of this information is shown below in Figure 1.

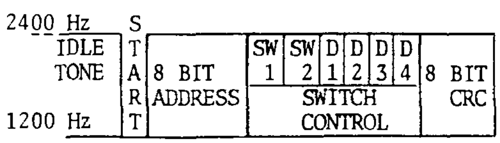

Figure 1. INTERROGATE WORD (23 BITS)

The transponder will reply to an interrogate if its own address matches that received, and the calculated CRC indicates that there were no transmission errors. The data returned consists of an address byte for confirmation, 4 byte values resulting from analog to digital conversion of 4 inputs, 4 binary bits indicating the status of internal or external alarms, 6 binary bits indicating switch settings, and a CRC byte. This is illustrated in Figure 2 below.

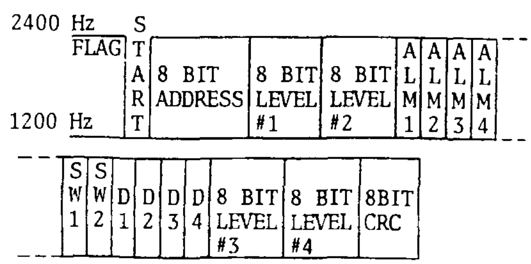

Figure 2. TRANSPOND WORD (59 BITS)

The diagram below provides an illustration of timing for the entire interrogation cycle.

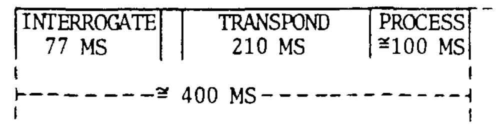

Figure 3. OVERALL INTERROGATION CYCLE

The user interface was specified to be as flexible as possible by the use of RS232C data ports. The ports are categorized as follows:

- Two dedicated work station terminals with associated alarm printers.
- Two dial-in work station ports for remote access to display screens.
- Two dial-out ports for access to remote signal level meters.
- One interface to another computer system responsible for overview graphics.

The status monitoring system is now equipped with 7 processor boards which run on an Intel Multibus. This allows the connection of 10 trunks to the system, each of which may contain up to 255 stations. A memory capacity of 1 Mb is provided. Non-volatile mass storage consists of a 35 Mb winchester drive and a cartridge tape which can store about 6 Mb. Both of these are used to store historical data from the system.

MULTIPLE TRUNK CONSIDERATIONS

There are two approaches that can be taken when multiple trunks must be monitored by a status monitor. The simplest and least expensive is to share one RF data modem with more than one trunk. This may not always be possible if the head-ends are separated, and also there is the inconvenience of level adjustments affecting the forward RF level on more than one trunk. Another method is to split and combine the transmit data and receive data respectively before modulation. This requires additional RF modems.

Both of the above methods were used by MTS before installation of the new monitoring system. As the number of total stations increases, the next logical addressing capability would be based on a 2 byte address. This would have required significant upgrades to existing transponders.

Even if one were to design or re-design transponders with an extended addressing capability, other pitfalls limit the practical size of the "one data I/O port" system. If the data speed is low, stations will be polled less frequently than desirable. The time to poll all stations for an arbitrary system of 1500 transponders at 400 ms per cycle would be 10 minutes. This assumes that all stations are scanned with equal frequency. It may be desirable to have certain stations such as end stations scanned more often. This will further lengthen the overall turn-around time.

Increasing the data rate normally means that the immunity to noise will decrease according to (1) assuming optimum design of modem characteristics for each case.

Immunity change = -10 log (new rate/Ref rate) (1)

A further limit exists when attempting to speed up the polling process. This is the processing time required after each poll. As more sophisticated alarm checking features are added, the processing time increases until at some point it becomes the dominant source of delay. The MTS status monitoring system requires approximately 100 ms for this overhead.

The above problems can be overcome by sharing the work load of normal polling among multiple I/O ports and processors. This solution maintained compatibility with existing transponders for the MTS system. A further advantage of splitting up the trunks for monitoring exists whenever a serious transmission impairment develops on a particular trunk. If this impairment prevents data transmission, only that trunk will be affected since the other trunks are physically separated.

OPERATING SYSTEM AND LANGUAGE

The status monitoring system includes both event driven functions and time driven functions. Event driven functions include the reporting of alarms as they occur and user access to informational screens. Time driven functions are required to handle storage of hourly and daily historical data and also to co-ordinate polling of remote signal level meters. The timing of the various functions is asynchronous in nature. This requires the use of a multi-tasking operating system. This system has 21 application tasks, excluding scanning tasks and operating system tasks. A useful feature is the ability to specify different priorities for different tasks. For example, the tasks that are responsible for generating alarm messages have a higher priority than those responsible for storing historical data to cartridge tape.

Flexible usage of memory is an important consideration, as many software tasks require extra memory only temporarily during certain functions. If all memory was allocated statically, additional hardware memory would be needed. Advantage can also be taken of the fact that not every trunk will contain the limit of 255 stations. The data-base for each trunk must reside in memory at all times. By locating each data-base dynamically, efficient use can be made of the pool of free memory.

The operating system used for the MTS status monitoring system is the Intel iRMX 86 object oriented operating system. The usual programming language for applications using this operating system is PL/M 86. A programming language for an application of this size must be geared toward high level modular style, for maintainability, and yet also allow some of the low level bit manipulation functions normally only present in assembly language. The ability to create large programs without overlays is also a desirable feature. One of the application modules in the system has in excess of 90K of object code.

SYSTEM ORGANIZATION

Processing responsibilities in the status monitoring system are divided between one master processor and six slave processors. Each of these processors (Intel 8088) interface with the multibus and have access to all of the main RAM memory. The master processor handles file accessing and the high level application tasks, while the slave processors provide I/O drivers for user ports and carry out the routine amplifier polling functions. A block diagram of the system is shown in Figure 4.

Each processor board contains EPROM memory of between 16K and 64K. The master processor uses its EPROM memory to automatically bootstrap load the monitoring system software. The slave processors use their EPROM code extensively even after system startup. The EPROM code and 4K of local RAM for each slave processor is not accessible by any other processor and does not require access to the multibus. This is an important advantage in that bus contention is minimized.

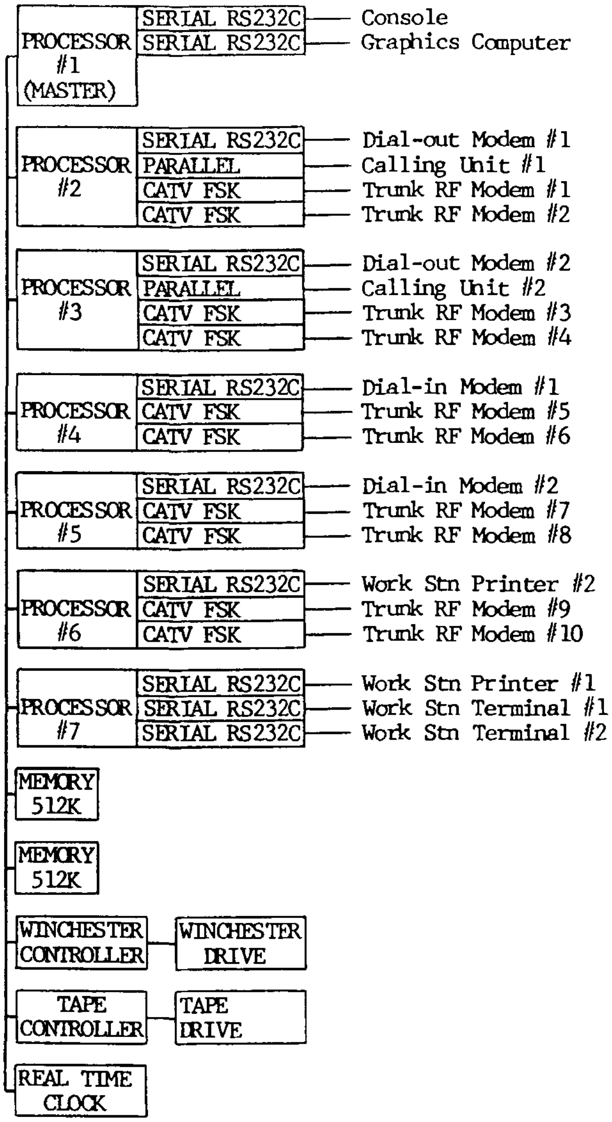

Fig. 4 - SYSTEM BLOCK DIAGRAM

Each processor runs its own local operating system, which except for one slave, includes multi-tasking features.

Tasks running on the master processor communicate with slave processor tasks via a custom operating system extension written by the supplier.

Scanning functions are facilitated by 5 of the slave processors. There are 2 intelligent scanning interfaces attached to each of these 5 slave processor boards. These are the interfaces that provide the Kansas City standard input and output data to the external RF modems. These interfaces each contain an 8 bit single chip micro-computer. Timing of the data for transmit and receive is accomplished by these interfaces. Each scanning board handles two interfaces and therefore two trunks by the use of separate tasks.

Scanning takes place with no intervention from the master computer other than instructions to start a particular scanning mode. The scanning firmware interacts with the memory resident data-base directly. The data-base is updated when valid data is received and new data is compared to alarm limits and alarm flags to determine if there is a change of alarm state. If a change of alarm state is detected, the scanning task will send an appropriate message to the master processor alarm task where it will be processed.

Each processor requires a certain amount of memory for its exclusive use. In this system the top 256K of memory is allocated for slave processor usage and interprocessor communication usage.

The master processor runs all the high level application tasks and requires a more complete compliment of operating system functional layers. The application software for the master computer can be broken down into four main modules:

1) Alarm generator
2) Work station
3) Background
4) Graphics computer interface.

The alarm generator processes messages sent to it from the scanning processors and issues alarms to the printers. Alarms are also stored in compressed format on a disk file. The alarm generator maintains counts of pending alarms for each section and station of the network.

User access via CRT terminals is provided by the workstation software. There are four user interfaces which have their own jobs and tasks. The work station screens provide overview alarm status during idle conditions and allow detailed viewing of CATV trunk measured parameters when requested.

Background tasks are responsible for storing historical data and for polling of signal level meters which are accessed by dial-up connections.

Each amplifier station has 128 bytes of data allocated in main memory. A compressed version (64 bytes) of each data-base entry is stored on disk files at the end of each hour, and then transferred to cartridge tape daily.

Polling of signal level meters is initiated every 20 minutes for the MTS status monitoring system. The software is designed to be compatible with Wavetek Sam IIID and Sam IV signal level meters. This software is currently being used to generate alarms when head-end television carrier levels exceed maintenance limits.

The graphics computer interface is a specific custom application used by MTS to integrate the Broadband Status Monitoring System with other alarm reporting systems. Its functions include sending change of alarm state messages and providing overall dumps of the status of a group of alarm points.

The above main modules are linked separately and are only bound together as an entire application by the operating system at run time. Approximately 256K memory is required for the entire operating system with application software. This does not include dynamic memory requirements such as task stacks and extra data segments. Dynamic memory of about 512K is available for these requirements as well as for the trunk data-bases.

SCANNING MODES

There are three types of scanning sequences used in the MTS status monitoring system.

1. Normal mode
2. Maintenance mode
3. Special purpose.

Any or all of these modes may be active at a particular time on a trunk. The scanning tasks are responsible for the sequencing of station polling in a manner that allows each mode shared access to the trunk.

Normal mode scanning is usually enabled continuously since this is the mode that checks the status of the network and generates alarms for out of limit conditions. The normal scanning sequence for this system consists of polling stations in two lists. The first list simply includes all stations of a trunk and the second is a subset of the first which consists of "priority" stations. Station polls alternate between these two lists resulting in two continuous scanning loops. Stations chosen as "priority" normally include the end stations of each trunk a well as stations that report critical alarms such as power supply alarms. This permits very rapid detection of outages and of selected critical alarms.

Maintenance mode scanning is invoked in response to an operator request to view the status of a single station. The same station is repeatedly polled and the data-base updated so that changes will be visible on the operators CRT terminal. Alarms are not generated by this mode.

Special purpose scanning includes functions such as amplifier balance checks and bridger switching. The Intercity Broadband Network in MTS uses feed-forward amplifiers. One of the useful features of feed-forward amplifiers, aside from their improved distortion performance, is their inherent redundancy. The main RF hybrid IC and the error RF hybrid IC must both fail before there is a loss of service. This feature is lost if an IC quietly fails and does not reveal any clues. Performance will only suffer noticeably when a significant number of stations have this problem.

The amplifier balance check modulates the power supply voltages of each of the RF hybrid IC's in a feed-forward station in a sequence. Balancing in a correctly functioning feed-forward stage minimizes the effect of this simulated impairment. Above normal modulation of a system carrier will be measurable, at the end of the trunk, during part of the sequence if one of the IC's is not functioning. This sequence can be performed manually using a spectrum analyzer at the end of the trunk or automatically if suitable detectors (performance monitors) are interfaced to system compatible transponder modules. The scanning firmware will update the data-base, and generate applicable alarms, if a "performance monitor" is used.

Bridger switching is one of the features that is yet to be implemented on this system. This also requires control information to be sent to the transponders. Its use is in locating the source of reverse trunk interference. This is accomplished by systematically switching off one reverse distribution leg at a time, under computer control, and noting when the interference changes at the head-end. Alternatively, the switches may be set up so that each leg is only attenuated (eg. 6 db) rather than completely cut off. Software or firmware could be designed to minimize operator input when a large number of switches are involved.

All of the scanning modes described perform integrity checks on the incoming data. If these checks conclude that errors may have occurred, then no action is taken other than to increment error counts for the station and trunks involved. The two checks are known as the cyclic redundancy check (CRC) and the station ID check.

The cyclic redundancy check used on the MTS system is an 8 bit CRC with a divisor polynomial of $X^8 + 1$. This check greatly minimizes the probability that random data will be interpreted as a correct transpond. This would normally occur about once in every 256 polls for completely random input data such as would be present with incoming noise without actual transponds. This is where the station ID check further reduces the probability of bad data being accepted. If the station address information received in the incoming transpond word does not match the station address that was requested in the interrogate, the data is rejected.

The above checking does have some limitations when data is received that is only partially corrupted. This occurs because the $X^8 + 1$ CRC polynomial has reduced performance when dealing with two errors in a transpond word. If two errors exist there is about 1 chance in 8 that the CRC will indicate correct data! The station ID will often still be intact in the case of only 2 errors within the entire transpond. Fortunately, this problem can be greatly reduced by choosing a more suitable 8 bit CRC polynomial. The use of a 16 bit CRC would render this problem insignificant, but might be too difficult to change on an existing system.

FAILURE REPORTING

Failures in this context refer to complete losses of service on part of a CATV trunk. The MTS Intercity Broadband Network imposed a challenge with respect to localizing this type of failure. The longest trunk monitored by the system is a straight line trunk consisting of 122 amplifier stations. The reverse trunk is regulated by AGC using a pilot originating at the end of the trunk. If a break occurs in the cable near the end of the trunk, the effect of all AGC stations back toward the head-end raises residual noise to high levels. For long trunks this build up is limited at the point where the AGC detectors determine that the noise level within the detector bandwidth is equal to the normal carrier level.

Normal interrogation cannot separate transponding stations from not transponding stations if CRC errors occur when polling stations before and after the discontinuity. In marginal cases extra interrogates could be attempted to provide statistically significant differences. This would slow down the fault locate process. The fault locating sequence on this system starts at the end of the trunk and works back toward the head-end until a transponding station is found. A more reliable method of determining transpond status was required to maximize speed and accuracy of this process.

A CRC error will usually be reported if there are any errors present in the incoming data. A more noise immune method of detecting the presence of the FSK data was developed specifically for fault locating purposes. This method uses the incoming 1200 Hz and 2400 Hz information directly rather than the 300 bps data. The coherent nature of this signal is utilized by digitally averaging the sliced FSK signal. The length of one cycle of the 1200 Hz tone is averaged 64 times. This cycle length or frame consists of 12 increments. The maximum value for each count is 64 and the minimum is 0. The maximum value is compared with the minimum value to determine if actual FSK tones are present. Examples of the results of this test are shown in Table 1. The absolute phase of the tones, at the beginning of the test, need not be zero as it is in the examples. Minimum drift and coherency, however, are essential requirements.

00	01	02	03	04	05	06	07	08	09	10	11	
64	64	64	64	64	64	64	0	0	0	0	0	1200 Hz only
64	64	64	0	0	0	64	64	64	0	0	0	2400 Hz only
64	64	64	32	32	32	32	32	32	0	0	0	1200/2400 Hz
56	53	57	29	34	31	32	30	33	13	10	15	1200/2400 Hz with noise

Table 1 - FSK DATA EXAMPLES

This test is performed in real time by the interface module firmware. It can be shown that if this test is performed 3 times during the transpond interval and suitable (max - min) thresholds are chosen for pass/fail, the following comparison can be made with the normal transpond method.

Probability of "noise only" being interpreted as data:

NOTE: $\log_{10}(p)$ is shown.

Normal method	-4.8 (ideal case/worst case -2.4)
FSK method	-5.5

Noise immunity improvement based on same probability of missing actual transponds for both cases.

Normal method	0 db (reference)
FSK	10 db (approx.)

Once a failure boundary has been found the status monitoring system issues a message specifying the range of stations affected. Other information is added when applicable. One example of this applies if the failure is on the edge of a powering boundary. Powering information is part of the data-base. Also, a re-check is done after every fault locate to determine if the failure was intermittent.

Conditions may exist on a trunk that cause the return data to be un-intelligible yet measurable by the "FSK" test. A warning message is issued when this condition is detected. This is necessary because some alarms may change state in the system without being detected by the status monitor until correct data is received.

CONCLUSION

A status monitoring system can improve service availability and decrease costs of maintenance on CATV systems. Limitations exist whenever one attempts to status monitor large networks with insufficient computer hardware at the head-end. Micro computers systems can be enhanced by sharing the processing load among multiple processors. This concept is now being used in applications that previously would have required the speed and sophistication of a mini computer. Software is a significant investment for the head-end computer, so expansion capability is an important consideration. Expansion capability refers to both the number of stations that can be accomodated and the ability to enhance software features in the future.