DESIGN CONSIDERATIONS FOR ENHANCEMENT OF A LARGE URBAN COAXIAL CABLE SYSTEM

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MANITOBA TELEPHONE SYSTEM

ABSTRACT

The large coaxial cable distribution system (CCDS) in Winnipeg, Manitoba, constructed as a 12 channel system in the late 1960s and now serving over 192,000 CATV subscribers, requires channel expansion for new television services and enhanced transmission performance to meet revised Department of Communications standards -- all within the context of providing a modern, multi-user, multi-service facility serving the broadband communication needs of various business, education and government users.

As the major communications common carrier in Manitoba, the Manitoba Telephone System (M.T.S.) has developed a plan for enhancement of the Winnipeg system based upon studies of alternative network configurations employing various communications technologies, such as Feedforward amplification, AM or FM Very High Capacity Microwave (VHCM), and analogue, digital or hybrid Fibre Optics.

Comparative study results forming the plan are presented along with details of the recommended network configuration. A purposeful commitment has been made to enhance the CCDS without adopting any distortion - masking techniques such as HRC or ICC phase-locking such that maximum flexibility is obtained to fully and flexibly use the network usefulness.

BACKGROUND

Two licenced CATV operators have provided service on a territorially - exclusive basis in Winnipeg with facilities constructed between 1967 and 1969. Both systems were designed for 220 MHz, 12 channel capacity using single ended amplification equipment and "Alucel" chemically expanded dielectric aluminum sheath cable, developed for CATV in 1964. These systems are now fully loaded with 12 television signals and face the need to add additional services such as national and regional pay television, specialized local programming, satellite delivered television programming and non-programming services such as security alarms. The larger of the two companies has identified a need for 17 additional television channels within the next 5 years, thereby producing an immediate need for enhancement of the existing facility to provide for midband and superband frequency spectrum usage.

As the provider of CCDS facilities in 34 communities throughout Manitoba, and a 279 mile coaxial cable Intercity Broadband Network (ICBN) linking 12 of those communities with Winnipeg, M.T.S. has been providing signal delivery for several non-CATV services on its coaxial cable facilities and is mandated to provide these functions in Winnipeg. PCM telephony, stereo music, Videotex, security alarms, closed circuit television, broadcast network television and data services have all been carried on provincial facilities and this same capability is now desired in Winnipeg.

PLANNING CONSIDERATIONS

The major consideration underlining the planning process was maximization of enhancement cost effectiveness through possible reuse of the existing cable and components, subject to their physical and electrical condition. To this end significant MTS-CATV operator joint testing was undertaken to evaluate the physical and electrical condition of existing active and passive devices from 5 to at least 300 MHz, with particular attention focussed on the shielding/RFI integrity of all components. Samples of the existing "Alucel" cable were submitted to an independent test laboratory for aging analysis of physical and electrical parameters.

Other major considerations in the planning process included the following:

a) Improved system reliability to reflect the carriage of essential services such as security alarms, and the increased customer expectations with respect to reliability of premium pay television services.

b) Significantly improved transmission performance at least meeting all requirements of the new Department of Communications (DOC)

Broadcast Procedure 23, Issue 2. This new specification significantly increases minimum subscriber drop levels, recognizing the mushrooming use of converters, and provides reference, for the first time, to Composite Triple Beat distortion.

c) Increased bandwidth and channel capacity to provide for maximum channel capacity within the constraint of cost-effectiveness, and with capability for future bi-directional operation, when required, through the addition of reverse amplifier modules and bridger switches.

d) Capability to provide an array of services (voice, video, data, facsimile, etc) and various modulation formats with maximum flexibility and usage of all frequency spectrum. The limitations and risks associated with employment of "heavy" phase-locking systems such as Harmonically Related Coherent (HRC) or Incrementally Coherent Carriers (ICC) were deemed unacceptable concepts.

e) The availability of status monitoring for system trunks is key to requisite system reliability and maintability in Winnipeg. Trunk amplifier stations are located in manholes on major traffic arteries. Trunk amplifier problems must necessarily be pinpointed accurately and quickly under these conditions. A paramount concern was the selection of a status monitoring system which could be integrated with the existing 256 amplifier ICBN monitor and, on an overall basis, integration of all CCDS alarms with the microwave radio, analogue and PCM carrier, satellite, switching and fibre optics alarms continuously monitored in the M.T.S. Provincial Central Alarm Centre in Winnipeg.

f) Maintainability by M.T.S. technicians supported by accurate and comprehensive records and effective communications is a major consideration.

g) The need for greatly improved RFI ingress protection to the entire CCDS, including subscriber drops, is inherent to the use of midband, superband and hyperband spectrum.

h) Given that the existing CCDS serves over 192,000 subscribers, with several signals being provided on a 24 hour basis, a vital planning consideration was logistics which would minimize service outages during the enhancement construction. While the defined logistics provide for outages only between 8:00 A.M. and 4:00 P.M., there may be surprises when construction starts.

NETWORK TOPOLOGY AND PERFORMANCE STANDARDS

The first step to defining the optimum enhanced CCDS configuration was to establish the worst case transmission performance standards for the overall facility. While the new Department of Communications BP-23, Issue 2, is a major input to this definition, M.T.S. CCDS specifications for rural broadband networks generally exceed the DOC standards and that same aspiration was embodied in the definition of standards for Winnipeg. Table 1 presents the overall worst case performance standards.

TABLE 1
WORST CASE WINNIPEG CCDS
TRANSMISSION PERFORMANCE STANDARDS

CARRIER TO NOISE RATIO (CNR)	43.0dB
CROSSMODULATION DISTORTION (35 CHANNELS PER NCTA 002-0267)	-53.0dB
SECOND ORDER DISTORTION	-67.0dB
WORST CASE COMPOSITE TRIPLE BEAT DISTORTION (CTB)	-55.0dB
HUM MODULATION (MEASURED PER DOC BP-23)	-50.0dB

An almost intuitive conclusion at the commencement of the planning process was that Winnipeg, by virtue of its population and physical size, would require a "hubbed" distribution plant with some type of supertrunk delivery of signals to each of the hubs from the master hubs near the CATV operator headends and studios. Given that assumption and the economic desirability of maximizing the size of each distribution hub area, it was possible to apportion the transmission performance specifications between the local (hub) distribution area and the supertrunk facility, with the latter requiring almost transparent performance in order to meet overall transmission specifications. Table 2 details the local distribution area worst case transmission performance specifications while Table 3 provides definition of these same parameters for the supertrunking system. The fundamental decision to avoid any service constraining distortion masking techniques, such as HRC or ICC phase-locking was embodied in the definition of transmission standards for all components of the CCDS.

TABLE 2 SUPERTRUNK DELIVERY SYSTEM PERFORMANCE SPECIFICATIONS	
CARRIER TO NOISE RATIO (CNR)	50.0dB
CROSSMODULATION DISTORTION (35 CHANNELS - PER NCTA 002-0267)	-64.0dB
SECOND ORDER DISTORTION	-77.0dB
WORST CASE COMPOSITE TRIPLE BEAT DISTORTION (CTB)	-71.0dB
HUM MODULATION (MEASURED PER DOC BP-23)	-53.0dB

TABLE 3 HUB DISTRIBUTION AREA WORST CASE TRANSMISSION PERFORMANCE SPECIFICATIONS	
CARRIER TO NOISE RATIO (CNR)	44.0dB
CROSSMODULATION DISTORTION (35 CHANNELS PER NCTA 002-0267)	-56.0dB
SECOND ORDER DISTORTION	-67.5dB
WORST CASE COMPOSITE TRIPLE BEAT DISTORTION (CTB)	-56.5dB
HUM MODULATION (MEASURED PER DOC BP-23)	-54.0dB

Physical sizing of the local distribution hub areas requires definition of the cable size and type to be used. Fortunately the results of the independent laboratory and joint MTS - CATV operator tests on the existing cable confirmed our desire to use as much of the existing coaxial cable as possible in the rebuild. (Our estimate of the replacement cost of the existing cable including all aerial, buried and underground plant is in the range of $10M to $15M). The disadvantage to the reuse is that because of its relatively high attenuation above 300 MHz (mainly due to the dielectric loss component), it is not cost-effectively used beyond a 300 MHz, 35 channel capability. These numbers, while trifling in the exciting world of US CATV franchising, are very respectable in the Canadian CATV market.

Given the local distribution area performance specifications and cable attenuations it was then possible to define an approximate geographical size for a local distribution area based upon the maximum allowable trunk and distribution cascades. Superimposition of this size on the city maps produce the conclusion that nine distribution hubs would be required for the enhanced facility. The CCDS hubs were not radically dissimilar to the MTS paired wire exchange areas, and nine central offices were natural choices as hub locations. Positive benefits to central office use include the availability of space for placement of modulators, processors, pilot carrier generators and associated equipment, emergency standby power generation and facility of interconnection with the paired wire telephone plant along with any existing carrier, fibre optics or radio trunk facilities.

While high-rise apartment blocks have been given secondary treatment in some CATV designs, with no overall consideration given to their effect on worst case transmission performance, it should be noted that the local distribution area specifications made provision for the inclusion of large Multiple Outlet Internal Distribution Systems (MOIDS) on the "tail end" of the distribution. Hence worst case transmission performance in a large high rise building is definitely considered within the bounds of the overall worst case subscriber transmission standards.

SUPERTRUNK TECHNOLOGY SELECTION

Selection of the optimum supertrunk configuration and technology was the most difficult exercise in the entire study because of the wide range of possible approaches and some significant pressure to integrate CATV and related services on new high capacity fibre optics trunk facilities being placed between several of the central offices. As a common carrier employing coaxial cable, fibre optics and various types of radio facilities throughout its service area, M.T.S. is very familiar with all technology options.

A. Very High Capacity Microwave (VHCM)

A number of options exist for the use of multi channel VHCM radio to provide, on a point to multi-point basis, CATV signal delivery to the hubs. The options considered were as follows:

i) 12 GHz AML in both high power and low power options.

ii) 15 GHz Double Sideband Amplitude Modulation (DSB AM)

iii) 15 GHz Frequency Modulation (FML).

iv) Reverse channel capability for both the 12 GHz and 15 GHz options was investigated using both 12 GHz and 15 GHz return options.

M.T.S. consideration of 15 GHz equipment was prompted by the close proximity to Winnipeg of a 12 GHz "digital radio corridor". The 12 GHz band is being reserved by the DOC within this corridor for future digital radio use by the TransCanada Telephone System.

In Canada the 12 GHz VHCM allocation provides for a total of 40 television channels, while only 32 channels are available in the 15 GHz VHCM band. Clearly the equipment required for 15 GHz operation is more expensive than the 12 GHz AML alternative.

B. Fibre Optics Transmission Systems (FOTS)

In early 1981 MTS issued an RFQ to a number of FOTS manufacturers for various alternative supertrunk configurations. Only two responses were received.

i) A U.S. manufacturer provided a quotation for an FDM-Frequency Modulation (FDM-FM) system using short wavelength fibre, with 5 channel per fibre loading and a maximum unrepeatered distance of 5km. This proposal would have required the use of intermediate repeaters.

ii) A Canadian manufacturer submitted two alternative proposals. Option 1 was for an FDM-FM system employing three video channels and associated audio per fibre, with an unrepeatered distance of 4km using shortwave length fibre. Option 2 was a High Order - Differential PCM (HO-DPCM) digital alternative with 2 channels per fibre each operating at 45 Mbps and four 6.3 Mb/s digital streams multiplexed onto a dedicated fibre with each 6.3 Mb/s stream carrying four audio channels. Using long wavelength fibre, an unrepeatered distance in excess of 10km was possible, thereby eliminating the need for repeaters. Future prospects of doubling the fibre capacity through Wave Division Multiplexing (WDM) and use of another "window" on the cable were also postulated.

iii) In early 1982 this manufacturer submitted another proposal using long wavelength fibre and Pulse Frequency Modulation (PFM) with WDM to provide 2 channels per fibre in an unrepeatered configuration.

iv) Another Canadian manufacturer, which has provided over 1700km of FOTS facilities for Saskatchewan's intercity CATV signal delivery network has been working closely with MTS in an attempt to provide cost competitive supertrunk facilities for Winnipeg. So far, the economics have not proven to be attractive due to the cost of terminal equipment.

All fibre optics proposals provided for a 40 channel capacity, nominally 35 forward and 5 reverse. The effects of repeater requirements are quite dramatic on the cost of the systems in that sophisticated remotely powered shelters with controlled environments are required.

While the analysis of comparative economics was based on equivalent loadings with standard NTSC vestigal sideband television channels, it was recognized that future utilization of the Winnipeg CCDS would involve transmission of FM broadcast signals, data signals with varying modulation formats and speeds, facsimile, pilot carriers, FM broadband video and other signals of varying "shapes and sizes". While modulators, demodulators and processors for coaxial cable transmission of these signals are generally available from a number of sources, and could likely be utilized with VHCM radio, there are no similar terminals available for FOTS usage. While this factor was not part of the economic analysis, it was recognized that FOTS cost, when adjusted to reflect the carriage of these ancillary and future services, would be progressively higher than for the other two alternatives. Provision of TV stereo audio will also be a problem with fibre and it is unlikely that any professional broadcaster would use the facility for television transmission at a 45 Mbps digital rate. (While professional standards for digital video are not yet fully established, postulated bit rates for quality signals exceed 300 Mbps).

C. Coaxial Cable Technology

It was clear from consideration of the specifications detailed in Table 3 that use of superlinear Feedforward amplifier technology would be required to facilitate coaxial cable supertrunking. Both 400 MHz, 52 channel and 300 MHz, 35 channel transmission options were considered. Various reverse transmission configurations were also studied employing sub low or mid split configurations.

Table 4 presents the comparative costs for the major technology options studied.

TABLE 4
COMPARATIVE COST RATIOS FOR MAJOR SUPERTRUNK TECHNOLOGY ALTERNATIVES

VHCM RADIO	
1) - 12 GHZ AML LOW POWER 32 CH FWD - 4 CH REV	1.87
2) - 12 GHZ AML HIGH POWER 32 CH FWD - 4 CH REV	2.15
3) - 15 GHZ DSB - AML * 30 CH FWD - 2 CH REV	1.92
4) - 15 GHZ FML * 30 CH FWD - 2 CH REV	2.48
FIBER OPTICS	
1) - ANALOGUE FDM-FM II 40 CH CABLE - TERMINALS FOR 17 CHS	1.83
2) - HYBRID PFM/WDM 40 CH CABLE - TERMINALS FOR 19 CH	3.33
3) - DIGITAL HD-DPCM 40 CH CABLE - TERMINALS FOR 17 CH	10.32
FEEDFORWARD COAXIAL	
1) - 400 MHZ - 52 CHS FWD, 4 CH REV	1.05
2) - 300 MHZ - 35 CHS FWD, 4 CH REV	1.00
NOTES * - MAXIMUM BAND CAPACITY IS 32 CH FWD AND REVERSE ** - COSTS FOR PROVISION OF CONTROL-LED ENVIRONMENT REPEATER SITES NOT INCLUDED	

OBSERVATIONS

The recommendation that a 400 MHz Feedforward supertrunk system be employed was based on considerations other than just comparative cost. Future costs for expansion of the supertrunk capacity in either forward or reverse directions using coaxial cable show advantages over either of the two other technologies. All VHCM alternatives suffer from potential problems with respect to blockages, transmission deterioration during heavy storms and the need for federal licencing. At present VHCM carriage of television and FM broadcast signals is allowed by the DOC, but there is some question as to licencing requirements for data, facsimile, and other transmission services which will be required in the future. Bidirectional operation with VHCM would not be as easy as with either cable alternative.

VHCM, and particularly FOTS, raise concerns as to their flexibility with use of various modulation formats (AM, SSB, PSK, DFSK, QPSK, FM, etc) for differing types of telecommunication services.

Reliability and maintainability of the FOTS and VHCM alternatives was projected as being somewhat higher than for coaxial cable supertrunks, in spite of the inherent redundancy of the Feedforward amplification process. However, considering all relavent technical, economic and future factors the Feedforward coaxial cable supertrunking option was seen as the optimum selection.

With both Canadian FOTS manufacturers having their FOTS research and development facilities within 500 miles of Winnipeg, contact is maintained with both of these companies to closely monitor FOTS technology development. While we have seen fibre costs decrease dramatically (one supplier's prices decreased from 90¢ per fibre metre to 70¢ per fibre metre in less than one year) and have seen various modulation schemes proposed to simplify transmission and eliminate repeaters, it remains clear that it is terminal equipment costs which place FOTS supertrunking economics in a unfavourable position with respect to other alternatives at this time and for the foreseeable future. That there will have to be major improvements made in terminal cost effectiveness in this technology before it will be competitive.

PLANNING STUDY CONCLUSIONS

As a result of the technical and economic analysis of the technology alternatives, the independent laboratory analysis, and the joint MTS - CATV operator field tests, the following conclusions emerged for the enhancement plan.

(a) The existing "Alucel" chemically-expanded dielectric cable would be used for area distribution and hub area trunking wherever possible.

(b) New area trunks, and extensions to existing trunks, would employ third generation Gas Injected Dielectric (GID) cables.

(c) The supertrunks would employ 19.0mm Fused Disc coaxial cable.

(d) Supertrunk facilities would be standby powered using the Uninterruptable Power Supplies (UPS) developed for use with the provincial ICBN. Standby powering of area trunk and distribution was not seen as requisite or economic at this time, largely in view of the very substantial battery requirements necessitated by the severe winter climate in Manitoba.

(e) A distributed-intelligence, multi microprocessor based status monitoring system employing Intel "multi-bus" technology is being developed for the Winnipeg CCDS such that it will be integrated with the existing ICBN status monitoring system and the MTS provincial alarm centre.

(f) Replacement of all passive devices and splices with devices employing radiation sleeve connectors.

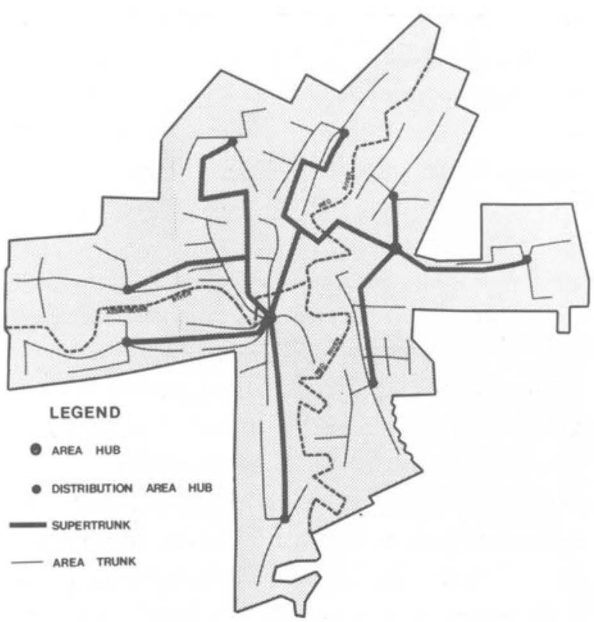
(g) Reconnectorization of all subscriber drop cables using connectors with extended integral ferrules and deep penetration mandrels.

(h) Use of 300 MHz push-pull amplifier technology on area trunks and distribution, with AGC employed in the distribution on some long cascades. Reverse transmission capability is provided for future implementation through module and bridger switch additions when required.

(i) Use of 400 MHz Feedforward amplifier supertrunks equipped with sub-low reverse transmission modules, upgradeable to mid-split as future service requirements dictate.

Figure 1 gives an overall view of the final network topology.

FIGURE 1



Those contemplating the construction of a new system in a city of similar size might ask what changes to the topology would result from a commitment to provide 400 MHz, 52 channel capacity, while still maintaining freedom from phase-lock techniques and the use of multi-channel microwave. These requirements would dictate the use of Feedforward for supertrunking, area trunking, bridgers and probably most of the distribution cascades. Replacement of Feedforward coaxial cable supertrunks with VHCM microwave would not change these requirements significantly since as the system-limiting Composite Triple Beat distortion problem is almost totally resident in the distribution, bridging and area trunks.

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