

Simultaneous Voice and Internet Data on Rural Subscriber Lines

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Abstract - We present the design of a system to provide rural telephone subscribers with simultaneous voice and Internet data service on a single telephone line. Simultaneous service allows a computer data connection to the Internet without impairing full use of the customer telephone station set. Our method employs a bi-directional frequency translation method together with standard "off-the-shelf" voiceband modems to implement voice and data frequency division multiplexing. Two experimental prototype frequency translators were constructed and used with 14.4, 28.8 and 33.6 kb/s modems. Operation was demonstrated on unloaded and on modified loaded lines at distances beyond the reach of ADSL equipment.

I. INTRODUCTION

With the extraordinary growth of the Internet and the World Wide Web, provision of data network access service to telephone customers is an important service objective for telephone companies (telcos). Telephone subscribers who access the Internet with standard voiceband modems tie up the telephone line, making it unavailable for incoming or outgoing phone calls. Since data signals from voiceband modems and voice share the same frequency band, only one of the two can be used at a given time, thus making simultaneous voice and data impossible. New digital subscriber line (DSL) technology now allows urban residents to obtain simultaneous voice and data service, but unfortunately, those living in *rural* areas are excluded due to technical limitations.

Asymmetric Digital Subscriber Line (ADSL) is a high speed network access method providing asymmetric data transmission capacities downstream to the customer's home (1.544-6.176 Mb/s) and upstream from the home (64-640 kb/s) [1]. ADSL is provided on the telephone line pair using a "data above voice" method and thus does not interfere with voice transmission. Due to attenuation of high data transmission frequencies, the maximum line length for ADSL service is 18,000 ft. (5487 m). Another possible method for providing Internet access and concurrent voice uses basic rate (144 kb/s) Integrated Services Digital Network (ISDN) transmission. Basic rate ISDN provides full-duplex data transmission on a single two-wire telephone line and requires transmission frequencies in excess of the voice band. Maximum telephone

line length for ISDN services is also 18,000 ft [2]. Concurrent voice service is provided by allocating some of the bit rate to carry digitized voice.

In telephony, rural subscribers are defined as being more than 18,000 ft (5487 m) away from the telephone company's central office (CO). A key technical problem is that rural telephone subscribers are serviced with long lines that require special conditioning to provide the telephone channel with acceptable voice quality. This conditioning is called "loading the line" and, while the voice frequency response is improved, frequencies greater than those required for "plain old telephone service" (POTS) are severely attenuated. This makes the channel unusable for the "data above voice" DSL technology. Rural residents, such as farm operators, have a significant economic interest in information that is available on the Internet. Commodity prices, weather information, buying and selling machinery, and obtaining difficult-to-find parts are examples of economically important information. This is especially true in areas like Manitoba, Saskatchewan, and Alberta where the rural population base is significant. A new method of providing simultaneous voice and data to these subscribers is therefore required.

Cable television (CATV) companies have recently entered the Internet access market with the introduction of cable modems. Cable modems use the same coaxial cables that provide television signals; this allows dedication of the telephone line to voice service. The cable network infrastructure, due to its expense, is limited only to urban areas where many customers can be accessed from relatively short runs of coaxial cable. This again excludes rural residents from simultaneous voice and data service.

Internet call waiting is a new service, offered by vendors such as Nortel and Lucent Technologies, that informs an on-line Internet user of an incoming phone call. When the user is online, an incoming telephone call is redirected to the Internet call waiting server which in turn generates an on-screen message informing the user [3]. The user may then redirect the call to another telephone or to voice mail or the user may directly answer the call. In this latter case, the data connection is terminated while the telephone conversation is occurring.

Although Internet call waiting is not *simultaneous* data and voice service, it does facilitate time sharing of Internet access and voice connection to the PSTN over a single telephone line.

Another alternative is digital simultaneous voice and data (DSVD) modems that allow the transfer of both data and voice between two locations. Voice is digitized and coded at the computer, then transmitted in the same channel and to the *same* destination as the data. The digitized voice and data are combined in the modem bitstream and that leaves approximately 20 kb/s available for data transmission during a voice conversation. During DSVD modem use, a standard telephone station set cannot be used concurrently to establish a normal voice call.

Presently, the only feasible simultaneous data and voice method available to rural residents is the installation of a second telephone line. This would allow one line to be dedicated to voice service while the other line could be used for data or voice transmission. An installation estimate (July 1998) from SaskTel customer service indicates that this option is rather expensive, with the initial installation of the line costing the customer between 500 to 800 dollars. Combining this cost with the monthly rental of the line (approximately 25 dollars) and Internet access fees makes this a prohibitively expensive option for most users.

II. SYSTEM PROPOSAL

The proposed system provides simultaneous voice and data to rural telephone subscribers on *one* twisted-pair telephone line. For each customer, there is a voiceband modem at the CO (which is connected to an internet service provider) and a similar modem at the customer premise. At both ends of the telephone line there are voice/data splitters and a frequency translator to connect the modems to the telephone line.

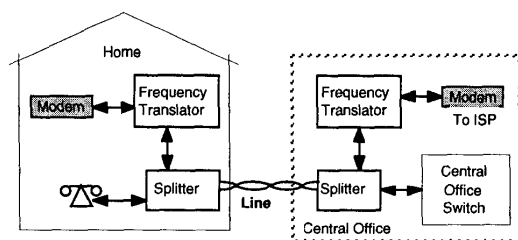


Figure. 1 Implementation of data-over-voice Internet access

The idea is to frequency translate the operating bandwidth of the modem from voice frequencies (approximately 200 to 3700 Hz) up to a higher band (5400 to 8900 Hz) for full-duplex communication on the telephone line. Frequency

translation is to be performed at both the internet service provider (ISP) and customer ends of the line. No hardware modifications are to be made to the modems although the modem settings may need to be changed.

To accommodate the higher frequencies required for this type of data transmission, it is necessary to decrease loading coil inductances to 14 mH in the subscriber line. Existing rural phone lines in the prairie provinces are equipped with 66 mH loading coils that bandlimit the channel to 4500 Hz. This technically simple procedure provides the requisite bandwidth by increasing the "cut-off" frequency to roughly 9 kHz. Unfortunately this change also increases the voiceband signal loss by a factor of 1.5 and therefore this method would require the inclusion of additional gain on very long rural lines.

III. VOICE/DATA BAND SPLITTER

Although the frequency-translated data signals are above the 4 kHz telephone voiceband, these data signals can still be heard through the telephone earpiece. Therefore, a voice/data splitter must also be included to ensure that the modem signal at the telephone station set is sufficiently weak. Furthermore, the splitter should exclude transmitted voice and telephone signals from the modem so as to not disrupt the data connection. Incoming and outgoing phone calls should be able to occur without breaking the data connection or slowing it down significantly. Additionally, the splitter needs to be constructed from *passive* components to ensure reliable operation of the telephone in the event of power failure. Note that its location in the household would be physically close to where the twisted-pair drop-wire enters the house.

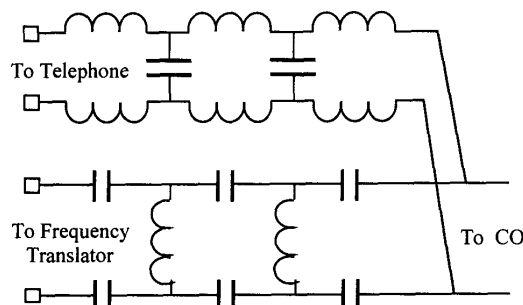


Figure. 2 Circuit of Voice/Data Splitter

The function and design of the splitter is similar to that of a crossover network in loudspeaker systems. In a crossover network, low frequencies are sent to the woofer via the lowpass filter section while high frequencies from the audio spectrum are directed through the highpass filter to the tweeter. The splitter must be able to perform filtering of both

downstream and upstream signals, therefore passive filters are selected since linear network reciprocity allows for bi-directional operation. Passive filters also allow telephone operation during power failure. Butterworth filters are preferred due to their constant input impedance which aids the hybrid coupler function. Furthermore, the filter impedance should match the line impedance in both the high and low frequency bands.

IV. FREQUENCY TRANSLATOR

A key element in the data above voice system in the frequency translator. This element must shift the modem signal frequencies upward for transmission on the line and must simultaneously select the data signals on the line and shift them downward for reception by the modem. Since frequency shifters are unidirectional devices, hybrid couplers are required at both ports of the frequency translator in order to interface with the 2-wire full-duplex modem and the 2-wire line. A block diagram of the frequency translator is shown in Figure 3.

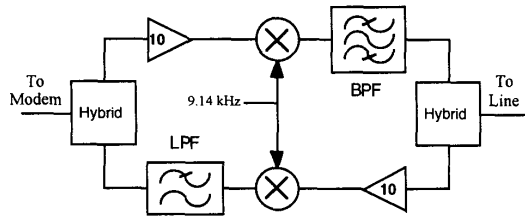


Figure 3 Block Diagram of Frequency Translator

The modem side hybrid coupler operates at voice frequencies and is able to achieve greater than 20 dB transmit/receive isolation by accurate matching to the 600 ohm termination impedance of the modem. The line side hybrid coupler operates at carrier frequencies (5400 - 8900 Hz) and has much poorer isolation (return loss) since the matching to the line impedance is much less accurate when compared to the 600 ohm modem. Nevertheless, substantial transmit and receive gain can be introduced in Figure 3 without encountering oscillations that result from 0 dB loop gain.

This design relies on the modems' echo cancellation circuitry to cancel return signals from the hybrid couplers. In our system, hybrid couplers introduce four sources of echo in the modem signal. They originate from the two hybrid couplers in the near end frequency translator and the two hybrid couplers in the far end hybrid couplers. These reflections are in addition to those caused by the splitter and any discontinuities in the transmission line (such as bridged taps). Successful connections in our testing demonstrate that

the modems' echo cancellers can still perform their function under these new operating conditions. Modem echo cancellers are designed to operate with near-end and far-end reflections and there is some concern that the delay caused by the sideband selecting filters will result in an intermediate delay echo that some modems may not be able to address.

It was decided to avoid transmitted carrier schemes in order to limit signal levels and reduce crosstalk between systems. We therefore selected single sideband (SSB) transmission which allow for non-synchronous local carriers at each end of the line. Modem standards [4] specify that received frequency offset of up to ± 7 Hz must be tolerated and this is well within the frequency tolerance of the low-cost ceramic resonators used in our implementation.

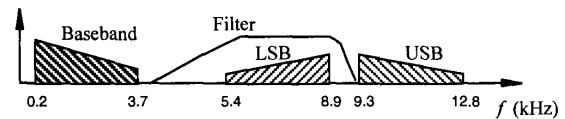


Figure 4 Spectrum for upward frequency translation

The modulator was implemented with a simple on/off CMOS switch and a bandpass filter to select the lower sideband about the carrier frequency. Selecting the lower sideband resulted in minimum filter requirements. In choosing the transmit frequencies, a "guardband" between the data and voice frequencies was included to simplify the design of the splitter. Reducing the transmit frequency would reduce the required loaded line bandwidth, increase the allowed loading coil inductance and thus decrease the voice frequency loss. On the other hand, this would necessitate higher order filters which would introduce more envelope delay distortion in the modem channel. The 9.13 kHz carrier frequency was chosen as a compromise. It should be noted that the most stringent requirement is for the low-pass portion of the filter. It must separate the lower sideband from the upper sideband and these sidebands are separated by less than 400 Hz.

V. PERFORMANCE MEASUREMENTS

The data above voice method was tested at Telecommunications Research Laboratories (TRLabs) to verify if two voiceband modems could establish communication with each other when connected through the frequency translator devices. Tests were conducted over a spooled twisted-pair telephone line loaded with 14 mH inductors at 4500 foot intervals. Test measurements and results included the modem connect speeds and the effects of POTS signals on the quality of the modem connection during data transmission. POTS signals included transmission and

signalling sources such as ringing signals, on/off-hook operation of the telephone, touch-tone dialing, and voice conversations.

The initial connect speeds for the US Robotics 33.6 kb/s modems were typically 24 or 26.4 kb/s. The Supra 28.8 kb/s modems connected at either 26.4 or 28.8 kb/s, and the USR/Digicom 14.4 kb/s modem pair always connected at 14.4 kb/s. After connection and during data file transfers, all modems operated within 95% of their top rated speed (presumably after some further adaptation and negotiating).

The Supra 28.8 kb/s and USR/Digicom 14.4 kb/s modems operated well with simultaneous telephone use, including the presence of numerous ringing signals and on/off hook operations. With a software change to only one of the built-in modem registers (register S10), these sources of impulse noise caused no terminations in the established connections, although the noise did temporarily halt the transmission of data. Normal operation resumed once the ringing and on/off hook operations ceased.

The USR 33.6 kb/s modems did, however, have difficulty maintaining connections in the presence of such impulse noise. The S10 register modification, although specifically designed for such disruptions, did not correct nor mitigate the problem. Rather, it was found that disabling the data compression setting in the modems was found to completely rectify the disconnect problem. The reason(s) why this solution worked remains to be determined.

The loaded line, while not being a source of excessive attenuation in the system, was removed temporarily from the setup to see whether any improvement would occur in the connect speeds. With only the modems, frequency translators, and splitters in the system, no increases were evident in the modem connect speeds.

Removing *one* of the splitters from the system did, however, improve the connect speeds, with USR modem connections established at either 26.4 or 28.8 kb/s. This may indicate that the group delay distortion introduced by filters (combined with the four echo sources from the four hybrid transformers in the data-over-voice system) is a factor in how fast the modems can connect. On the other hand, the failure of the USR modems to achieve their *maximum* connect speeds could be a result of the echo cancelers' inability to use all of the available 3500 Hz bandwidth allocated in the new transmission channel.

The sideband filter realizes only 23 dB attenuation in the transition region between 3.7 kHz and 5.4 kHz. The resulting low SNR in the modem signal was believed to be a possible source of the less-than-maximum connect speeds. Therefore,

higher order filters were designed to replace the original lowpass filters. Although the new filters provided about 10 dB more attenuation in the transition region, no improvements were observed in the modem connect speeds.

Staff and students at TRILabs were recruited to listen to the telephone during file transfers between computers. Although perceptible background noise was always present on the telephone in the experimental system, no listener reported hearing any difference in noise between the simultaneous voice/data and voice-only cases. Suppression of the 5.4-to-8.9 kHz modem signal at the telephone station set is indicative of the performance of the voice/data splitter.

VI. CONCLUSION

We have demonstrated data above voice operation on loaded lines using off-the-shelf voiceband modems and bidirectional frequency translators. We have investigated the ability of the modem echo cancellers to cope with additional sources of echo, delay and frequency error.

ACKNOWLEDGMENT

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