# The Feasibility Study of Transporting IS-95 CDMA Signals Over HFC Networks

Y. M. Lin and W. I. Way, *Senior Member, IEEE*

***Abstract*— This letter studies the feasibility of transmitting IS-95 code-division multiple-access (CDMA) wireless signals in hybrid-fiber-coax (HFC) networks. Capacity estimation of an HFC optical node-based CDMA cellular systems using a return-path channel model is provided. In addition to multiple-access interference in IS-95 CDMA networks, the return-path channel model takes into account ingress noise, impulsive noise, and microreflections in a coaxial cable transmission system; and laser diode clipping-induced intermodulation noise in an optical fiber link.**

***Index Terms*— Code-division multiple-access, IS-95, hybrid-fiber-coax, laser clipping.**

## I. Introduction

HYBRID-FIBER-COAX (HFC) networks are bound to play an important role in bringing interactive broadband services to subscribers. Parallel to this HFC network evolution process is the miniaturization of cell size in today's cellular and tomorrow's personal communication service wireless networks to increase network capacity. IS-95 CDMA voice-application-oriented systems, in particular, have been standardized by EIA/TIA [1], and have been or will soon be operated in many countries around the world. Meanwhile, synchronized CDMA techniques have been demonstrated in HFC systems [2], [3]. Therefore, the purpose of this letter is to study, via computer simulation, whether the HFC network infrastructure can be utilized to provide IS-95 CDMA services, especially to accommodate the increasing number of radio antenna ports (RAP's) for wireless access. RAP's (which include RF up- and down-converters) can be installed in an HFC network, as shown in Fig. 1. Fig. 1 is applicable to situations such as (1) to extend cell coverage or to resolve a "blind-zone" coverage problem, and (2) to increase resource sharing in low-traffic service areas.

We want to examine the technical feasibility of the transmission system from the RAP's to the CATV headend. In particular, we want to study how well IS-95 CDMA signals can tolerate the abundant ingress and impulse noise sources in the return-path spectrum (5–42 MHz in North American CATV Systems), and how the return-path-laser-clipping induced intermodulation noise may affect the IS-95 signals. Downstream HFC transmission is not considered because: 1) the impulse noise induced by a weakly clipped downstream laser can be easily overcome by the large processing gain and interleaver depth of an IS-95 signal and 2) little RF ingress or impulse noise exists in the frequency range between 450 MHz and 1 GHz.

Manuscript received July 16, 1998; revised November 17, 1998. This work was supported by the National Science Council, Republic of China, under Contract NSC87-2215-E09-019.

The authors are with the Department of Communication Engineering, National Chiao-Tung University, Hsinchu, Taiwan, R.O.C.

Publisher Item Identifier S 1041-1135(99)04971-X.

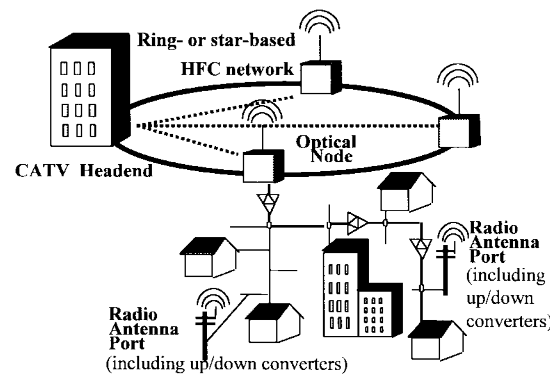


Fig. 1. Wireless access in HFC system architecture.

## II. Overall System Simulation Block Diagram

The overall system simulation block diagram is given in Fig. 2. It consists of a pair of IS-95 CDMA uplink transmitter and receiver, multiple access interference (MAI) inherent to CDMA systems, and a transmission channel model. The channel model includes ingress noise, impulse noise, and microreflections in a coaxial system, and return-path laser clipping. We will start with a brief review of the uplink IS-95 CDMA system.

### *A. Uplink IS-95 CDMA System*

As shown in Fig. 2, the 9.6 kbps baseband data is first sent to a rate—1/3 constraint length—9 convolutional encoder, and then to a block interleaver with interleaving parameters $32 \times 18$, to obtain an output symbol rate of 28.8 ks/s. Subsequently, a 64-ary orthogonal modulation is performed by selecting a row (out of 64 rows) of 64-bit Walsh code indexed based on every six incoming data bits (with 64 possible combinations). At this point, the symbol rate becomes 307.2 ksps (=28.8/6 $\times$ 64). The coded symbol is then spread and scrambled by mixing with the 1.2288 Mbps long code (period $2^{42}-1$). The scrambled data stream is spread further by simultaneously spreading the data stream in quadrature with short-length (period $2^{15}$) sequences. The resulting quadrature channels are

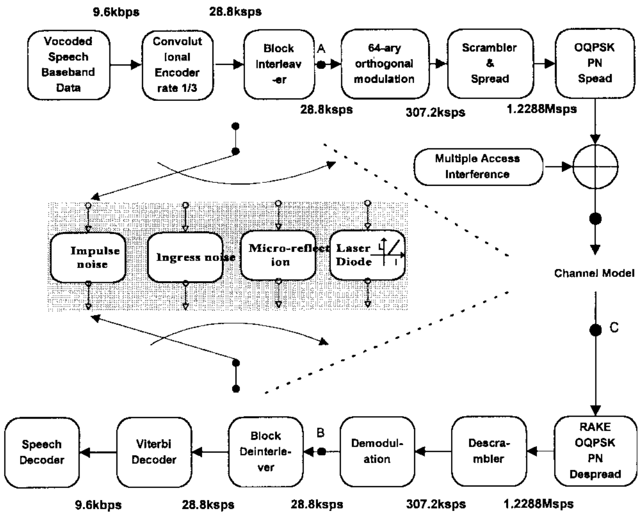


Fig. 2. Uplink IS-95 block diagram.

applied to an OQPSK modulator for I/Q filtering and mixing up to the carrier frequency. The receiver part of an IS-95 uplink is just the reverse of the transmitter. Synchronization is assumed to be achieved by the downlink pilot tone in IS-95 systems. The RAKE receiver is not modeled in our computer simulation because we assume flat frequency fading for the radio propagation, and because a RAKE receiver cannot resolve any microreflection-induced multipath delay less than about 1 $\mu$s (typical delays among microreflection-induced multipaths are less than a few hundred nanoseconds [5]).

### *B. Theoretical Versus Simulation Capacity of Spread Spectrum 64-ary Orthogonal Modulation*

The theoretical capacity of a spread spectrum 64-ary orthogonal modulation (from point A to B in Fig. 2) is estimated in order to calibrate our computer simulation results. The relation between the number of users and MAI-limited bit-error rate (BER) is given by [6]. The calculated results are shown in Fig. 3. They match fairly well with our computer simulation results. In addition, we can see that when the received $(E_b/N_o)_r$ (the ratio of bit energy to white noise spectral density) per user measured at point B in Fig. 2 is increased from 8 to ~22 dB, there is a significant improvement in the BER performance for the same number of users. However, when $(E_b/N_o)_r$ per user is increased beyond ~22 dB, negligible BER improvement can be obtained. Therefore, for the spread spectrum 64-ary orthogonal modulation system shown in Fig. 2 (point A to B), we can set the minimum required $(E_b/N_o)_r$ per user to be 22 dB.

## III. COMPUTER SIMULATION RESULTS

Having established the confidence in our simulation results for 64-ary orthogonal modulation, we then add the convolutional codec and interleaver/deinterleaver blocks to complete the entire simulation link. Various channel degradation factors shown in Fig. 2 are added one at a time. The results are as follows.

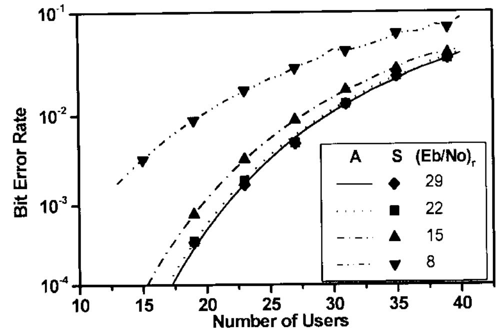


Fig. 3. Comparison of analytical (A) and simulation (S) results for the BER performance of 64-ary modulation with rectangular pulse (without counting convolutional codec and interleaver/deinterleaver in Fig. 2).

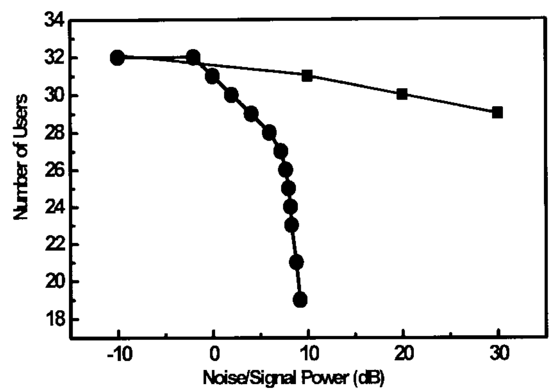


Fig. 4. Effect of impulse (square) noise and ingress (circle) noise on IS-95 capacity.

### *A. IS-95 Capacity Degradation Due to Multiple Access Interference*

The capacity is first estimated considering only added white Gaussian noise (AWGN) and MAI. Under a typical BER requirement for voice transmission of $10^{-3}$, we find that IS-95 can have at most 32 users simultaneously on line in a single CDMA bandwidth, i.e., 1.25 MHz, at $(E_b/N_o)_r$ per user $\geq$22 dB.

For an IS-95 uplink, the commonly cited criterion is $(E_b/(N_o + I_o))_r$ per user $=$ 6 dB [4]. Since the processing gain in an IS-95 uplink is 128 (=1.2288 Mbps–9.6 kbps) or 21 dB, the required $(E_b/I_o)_r$ per user before despreading can be as low as $-15$ dB when MAI dominates over white noise [7]. However, $(E_b/I_o)_r = -15$ dB is equivalent to a condition with about 31 interfering users. This is quite consistent with our simulation results of total 32 users.

### *B. IS-95 Capacity Degradation Due to Impulse Noise*

We model the impulse noise as a Poisson process whose amplitude variation is a Gaussian random variable. The duration of each impulse is uniformly distributed between 2 to 4 $\mu$s. The Poisson process arrival rate is 200 times per second. The noise power is calculated as a normalized power with respect to the signal power. The capacity reduction due to impulse noise is shown in Fig. 4. We observe that the effect of a impulse noise with such a short duration only reduces the IS-95 capacity from 32 to 29, even when the noise power is 30 dB higher than that of the signal power. This is because

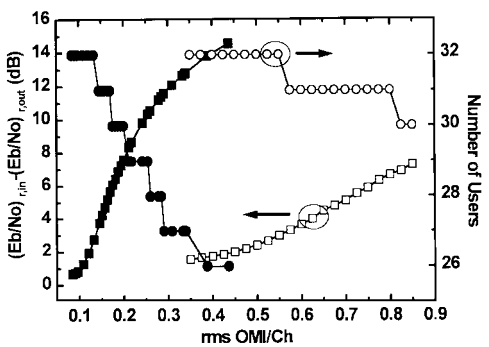


Fig. 5. $(E_b/N_o)_r$ reduction and capacity as a function of rms OMI for single (open) and 17-channel IS-95 (solid) signal.

the short impulse noise can only cause about 2 to 5 symbol errors (for a symbol rate of 1.2288 Mbps), and because Viterbi decoder of the uplink IS-95 system is very powerful (it has a free distance of 18). We also note that the bit error rate caused by a burst noise with a 30-$\mu$s mean duration and interarrival time of 10 s is about $10^{-5}$ for an IS-95 signal, which is more than sufficient for this voice-grade signal.

### C. IS-95 Capacity Degradation Due to Ingress Noise

The simulation results of capacity reduction as a function of the ratio of ingress noise power and signal power is shown in Fig. 4. The results show that the CDMA system capacity starts to reduce when the ingress noise power increases above 0-dB relative to the signal power (at this level, the ingress noise causes the same effect as a new interfering user on the already fully loaded 32-user system). Even so, the capacity reduces only 20% when the ingress noise power is above the signal power by 7.5 dB, because the narrow-band noise is spread into a less damaging white-noise-like interference in the receiver.

### D. IS-95 Capacity Degradation Due to Multipath Interference

In the coaxial cable part of HFC systems, relative delays due to multiple reflections is less than 1 $\mu$s. In our computer simulation, we model a "strong reflection" case [5] which has a second-path signal whose power is 13 dB lower than that of the main path, and has a delay of 600 ns with respect to the main path. The simulation results show that only two more users are lost due to the strong reflection.

### E. Laser Clipping Noise

The strong-clipping phenomenon in a return-path laser [8], [9] induces white-noise-like intermodulations and can set an upper bound of the optical modulation index (OMI) of the CDMA signals. We assume that the laser has an ideal output light power versus bias current characteristics ($L$–$I$ curve), as shown in Fig. 2. The simulation results are shown in Fig. 5 for single channel and 17 channels of IS-95 signals. The 17 channels (each occupying a 2-MHz bandwidth, including guard bands) can fully occupy the 5–40-MHz return path band of an HFC system. Both figures show the degradation of $(E_b/N_o)_r(=(E_b/N_o)_{r,\mathrm{in}} - (E_b/N_o)_{r,\mathrm{out}})$ and the resultant capacity as a function of the rms OMI/channel, where $(E_b/N_o)_{r,\mathrm{in}}$ and $(E_b/N_o)_{r,\mathrm{out}}$ represent the $(E_b/N_o)_r$ at the input and output of a clipped-laser diode, respectively. Since the strong-clipping-induced in-band intermodulation noise is Gaussian-like, which cannot be despread by the IS-95 receiver, we can see that both $(E_b/N_o)_{r,\mathrm{out}}$ and the corresponding capacity decrease quickly as OMI/channel increases. If 10% capacity reduction is allowed, the rms OMI/ch for 17 IS-95 channels should be kept below 0.26. If no capacity reduction is allowed, the rms OMI/ch for single and 17 IS-95 channels should be kept below 0.55 and 0.13, respectively. Note that to maintain a CNR of ~5.1 dB $(=(E_b/N_o)_r * 28.8k/BW)$, where $(E_b/N_o)_r = 22$ dB and $BW = 2$ MHz) for an IS-95 signal at point C in Fig. 2, the system equivalent RIN level can be as high as $-89$ dB/Hz for an OMI/ch = 0.13. This high tolerable relative intensity noise level indicates that the system noise margin is quite large, and therefore typical system Gaussian noise can be neglected when compared with other factors considered in this paper.

## IV. Conclusion

The feasibility of transmitting wireless IS-95 signals in HFC networks is studied in this paper. Various impairments in HFC return-path are discussed and their effects on wireless link capacity are estimated through computer simulation. We observe that the impulse or burst noise normally encountered in HFC systems does not seriously affect the capacity of IS-95 systems, thanks to the powerful coding scheme. When considering ingress noise, we note that when there is a strong in-band narrow-band noise, the IS-95 system capacity does decrease, but can still support some active users. Microreflections in coaxial cable were found to contribute to a small capacity reduction. Finally, the clipping-induced intermodulation noise has to be carefully minimized by controlling the OMI/ch of each IS-95 signal. When no capacity degradation is allowed, the rms OMI/ch for single and 17 IS-95 channels should be kept below 0.55 and 0.13, respectively. For the case of 17 IS-95 channels, the total system capacity can reach $32 \times 17 = 544$ users.

## References


[1] TIA/EIA/IS-95, "Mobile station-base station compatibility standard for dual-mode wideband spread spectrum cellular system," Telecommunication Industry Association, July 1993.

[2] CableLabs, Advanced Modulation Systems Technology Reports, "Terayon cable modem transmission system test results." [On-line]. Available HTTP: http://www.cablelabs.com/terayon.pdf.

[3] S. Rakib, "Synchronous-CDMA: The solution for high-speed data over cable," in *45th Annu. NCTA Conv.*, Tech. Papers, pp. 176–181, 1996.

[4] R. L. Peterson, R. W. Ziemer, D. E. Borth, *Introduction to Spread Spectrum Communications.* Englewood Cliffs, NJ: Prentice-Hall, 1995, p. 536.

[5] K. Laudel, E. Tsui, J. Harp, A. Chun, and J. Robinson, "Performance of a 256-QAM demodulator/equalizer in a cable environment," in *43th NCTA Annu. Conv. and Expo*, Tech. Papers, New Orleans, LA, 1994, pp. 283–304.

[6] H. Zhang and D. Rutkowski, "Performance analysis of a spread spectrum $M$-ary orthogonal modulation under multipath Fading," in *Proc. ICCS'94 Conf.*, Singapore, vol. 2, pp. 602–606.

[7] R. Padovani, "Reverse link performance of IS-95 based cellular systems," *IEEE Personal Commun. Mag.*, 1994, 3rd quarter.

[8] P. Y. Chiang and W. I. Way, "Ultimate capacity of a laser diode in transporting multichannel M-QAM signals," *J. Lightwave Technol.*, vol. 15, pp. 1914–1924, Oct. 1997.

[9] H. Kim, J. M. Cheong, C.-H. Lee, and Y. C. Chung, "Passive optical network for microcellular CDMA personal communication services," *IEEE Photon. Technol. Lett.*, vol. 10, pp. 1641–1643, Nov. 1998.