Integrated Wireless PCS - Hybrid Fiber Coax Network Architecture

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ABSTRACT

The following paper explores the trends, issues and opportunities for telephony service providers to leverage broadband Hybrid Fiber Coax (HFC) networks to deliver integrated wired and wireless services to consumers. In particular, specific attention is focused on the industry trend toward the use of HFC networks; the complementary architecture; and the benefits as well as issues associated with the use of HFC networks for the integration of personal communications services. This paper will include an overview of Motorola, STV, TCI and Cox's PCS trial over the cable plant in San Diego and Dallas using GSM and CDMA technologies.

INTRODUCTION: TELEPHONY IS GOING BROADBAND

At present, there are three service providers with direct connections to the home: telephone, power and cable. As each of these respective industries make architecture decisions to compete for a share of the $120 billion telephony market, HFC networks will continue to expand, improve and proliferate. Additionally, with the introduction of new services and spectrum hungry applications, such as: virtual shopping, video telephony and megabit network access, the requirement for telephony bandwidth will continue to grow. Recognizing the prevalence of and bandwidth available from HFC networks, many companies are now exploring the use of the HFC plant for delivering not only end user services but also distributing radio frequency (RF) signals for wireless telephony.

THE MOTOROLA EXPERIENCE

Motorola has performed trials with both CDMA and GSM access technologies in live cable systems using two different approaches for wireless signal distribution. Specifically, Motorola has trialed GSM RF transport with Cox Cable Communications in San Diego, CA and more recently CDMA RF transport and wireless integrated baseband transport with Tele-Communications, Inc. (TCI) in Dallas, TX and Arlington Heights, IL.

The remaining sections of this paper describe the similarities between HFC and wireless networks as well as the advantages and issues associated with HFC wireless network integration.

HFC ARCHITECTURE

Cable passes greater than 95 percent of the homes in the United States with approximately 60 million homes subscribing to cable services. The main operators of these HFC networks are cable operators.

Cable operators use the cable plant, a broadband bi-directional pipe, to simultaneously deliver multiple services to consumers. Currently, cable operators are upgrading their existing infrastructure, as illustrated in Figure 1, to provide up to 700 MHz of bandwidth in the downstream direction (to the home) and 37 MHz of upstream bandwidth (from the subscriber to the cable operator.

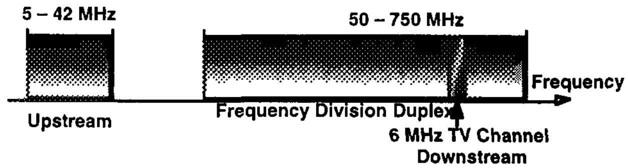

Figure 1.

As shown in Figure 2, the HFC cable plant is divided into three fundamental components:

- Headend
- Fiber Node
- Coax Feeder-Drop Distribution

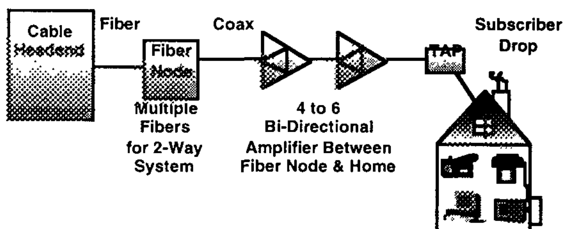

Figure 2.

The Headend

At the headend, all video signals are combined from satellite receivers, local television receivers, fiber optics and other headends for distribution to the subscriber. The headend is the concentration point for the HFC network. Local commercials may also be added at the headend.

Fiber Nodes

Banks of lasers located at the headend distribute the video signals to fiber nodes. Each fiber node typically supports between 500 and 2,000 homes and is spaced between one and three miles apart. At the fiber node, the video signals are converted from light back to RF for use in the coax plant.

Coax Feeder-Drop Distribution

The coax plant is distributed using bi-directional amplifiers to the home subscriber. Prior to the use of HFC cable plants, 20 amplifiers may have been used from the headend to a subscriber's home. This distribution caused the system to be less reliable since any one amplifier outage would affect service on the entire coax run. With the implementation of HFC into the cable plant, the number of amplifiers between the headend and a subscriber's premise was significantly reduced to contain commonly less than five amplifiers.

To date, much discussion in the industry has focused on how far toward the home fiber should be run. The contention revolves around the added cost of fiber versus coax; consumer demand for bandwidth; and network reliability. In some cases the application and issues of economics reliability suggest minimal, if any, coax in the network. In the case where no coax is utilized the network can be broadly classed as Fiber To The Home or a FTTH network. Popular discussion introduces the less expensive alternative Fiber To The Curb or FTTC architecture.

Under scrutiny, both FTTH and FTTC reveal themselves as variants of the same broader classification — hybrid fiber coax network. The only differentiation between these two classifications is the amount of bandwidth and associated cost. In the traditional cable industry, there is a great deal of discussion related to the optimum amount of bandwidth required for meeting the customer's ever increasing thirst for applications. In cable language this is described as the number of homes served per fiber node.

At present, it appears that the cable industry is settling on 600 home fiber nodes. At 600 home fiber nodes, cable could be described as Fiber To The Neighborhood or FTTN. Stated alternately, fiber to the home, fiber to the curb and today's traditional cable networks are all variations of a similar architecture intended to deliver sufficient bandwidth to the home to meet both today's and tomorrow's service demands. The key differentiation being the smaller the number of homes served from any one fiber means the greater the available bandwidth and cost for the served area.

Beyond today's cable Multiple System Operators (MSOs) some of the Regional Bell Operating companies have begun deploying HFC networks as well. Most recently, Pacific Bell, Bell Atlantic, Ameritech and US WEST have all announced, or are in the process of building, HFC networks. This when coupled with Sprint's recent partnering with Comcast, Cox Cable Communications and TCI for Personal Communication Services (PCS), demonstrates significant industry momentum toward HFC as the chosen architecture for delivering the next generation of telephony services.

WIRELESS ARCHITECTURE

There is a great deal of similarity between today's wireless systems and HFC networks. Figure 3 depicts a current generic wireless network. As shown, the architecture is composed of three main subsystems: network, switching and radio.

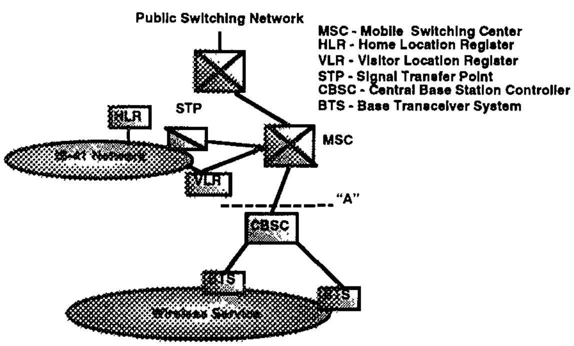

Figure 3. A-Interface and Architecture

In the radio subsystem, the cell sites or Base Transceiver Station(s) (BTS(s)) are connected to Centralized Base Station Controller(s) (CBSC(s)) via T1 interfaces. There are two types of cell sites: macro and micro.

A macrocell typically uses high gain sectored antennas mounted on 100 to 300 foot towers to provide between one and 10 miles of coverage. The difference in range is primarily a result of tower height, power output, terrain and morphologic conditions (urban, suburban and rural environment). A typical macrocell may consist of between 50 and 100 traffic channels capable of supporting between 2,000 and 5,000 subscribers. The traditional macrocell uses a shelter or in-building space to contain the radio equipment. In contrast, a microcell typically uses omni antennas placed on a smaller tower or the top of a building (under 100 feet). The range of the microcell is under one mile with the microcell radio equipment in a small outdoor enclosure about the size of a small refrigerator that can be placed easily in many outdoor environments. The microcell may have from eight to 20 traffic channels and most likely supports less than 1,000 subscribers.

System deployments over 100 macro and microcells are often needed to cover a large metropolitan city. This requires an extensive distribution system to interconnect the BTS(s) to the CBSC(s). The CBSC concentrates the T1s and controls the mobility aspects of the radio subsystem. The Mobile Switching Center (MSC) is the interface between the CBSC, the Public Switched Telephone Network (PSTN) and other wireless networks. The MSC further concentrates the T1 interconnect from the CBSC(s). The MSCs in today's wireless systems are unique to handle the special mobility aspects of the wireless switching systems.

Like most system architecture the wireless system continually evolves to best serve end customer needs. The next generation of architecture looks to more fully integrate the wired and wireless networks through the reuse of wired network switching and intelligent peripherals. Although not fully explored in this paper this architecture is similar in its similarity with HFC networks as well as the benefits associated with HFC-wireless network integration.

INTEGRATION OF HFC AND WIRELESS NETWORKS

There is an interesting similarity between HFC networks and wireless networks. Typically in today's wireless network there is a single MSC per city. The wireless MSC is analogous to the main headend located in each franchise or city. The HFC network also connects to individual headends which are intended to support between 20 and 100 fiber nodes. Each fiber node can support up to 2,000 homes. The headend and fiber node are very similar in function and size with wireless systems base station controllers and cells.

APPROACHES FOR USING HFC NETWORKS FOR PCS

Over the past few years, wireless operators and vendors have investigated the use of the cable plant as a distribution system for wireless telephony. In general, there are two techniques to leverage the cable plant infrastructure for PCS:

- RF transport
- Baseband Transport

RF Transport

RF transport uses the cable plant to distribute RF energy (that would normally go to an antenna of a macrocell) through the cable plant to specific points on the cable plant and radiates this RF energy by simulcasting it to a larger coverage area than could be covered by a traditional macrocell. In an alternate approach, baseband transport is integrated with microcells to provide cable based backhaul instead of the more traditional leased line or microwave.

Cox Cable Communications has been a leader in the development of wireless - HFC network integration and was granted a PCS pioneers preference license for its work in the integration of PCS with cable. A significant portion of Cox's activities were RF transport demonstrations with multiple vendors. In particular the Motorola/Cox trial in San Diego used RF transport to integrate GSM RF signals with the cable plant.

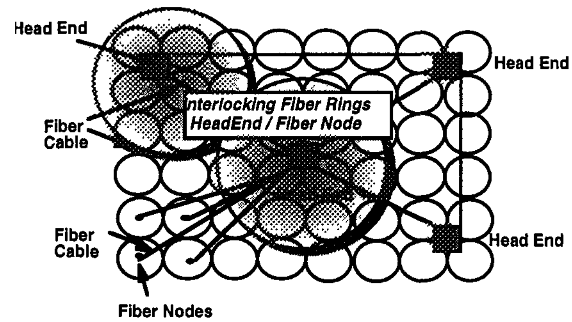

Figure 4.

As shown in Figure 4, the trial used what was earlier called RAD/RASP (Remote Antenna Driver / Remote Antenna Signal Processor) or is now referred to as CMI/HIC (Cable Microcell Integrator/Headend Interface Converters) equipment to transport RF energy from a base station through the cable plant to an antenna system. Additionally, Motorola has performed a CDMA CMI/HIC trial as well as baseband transport with TCI in Dallas, TX and Arlington Heights, IL respectively. The experience and results of these trials have been combined with the Cox Cable Communications trial to formulate many of the conclusions in this paper. Further information regarding the Cox Cable Communications GSM CMI/HIC trial is available in the FCC Quarterly Report entitled, <u>Cox Enterprises, Inc. Sixteenth Quarterly Progress Report to the FCC for Experimental Licenses, March 1995</u>.

CMI/HIC

With CMI/HIC a HIC is co-located at the base and converts RF energy (CDMA, GSM or other air interfaces), that would normally go to an antenna, to an upstream and downstream frequency allocated for wireless communication on the cable plant. The RF energy is injected into the cable plant at a very low signal level (10 dB below a normal video channel). In the cable plant, CMIs convert the RF energy at cable plant frequencies back to the original frequency of the wireless system. The CMI is a 40 pound box that is located on the cable coax strand at an average of 23 feet above the ground level.

To facilitate understanding, Table 1 delineates up- and down-frequency conversions for a CMI/HIC system.

Table 1. Representative Frequency Conversions for CMI/HIC System

CMI/HIC System Component	Down Stream	Up-stream
Base Station Frequency	1862.2 MHz	1942.2 MHz
Cable Plant Frequency	541.9 MHz	20.5, 23.5 MHz
CMI Frequency	1862.2 MHz	1942.2 MHz
Portable Frequency	1862.2 MHz	1942.2 MHz

In this example, a base station modulates a PCS RF carrier at 1942.2 MHz. The RF energy is then sent via transmission line to the HIC which converts it to 541.9 MHz. The signal then travels through the cable plant to a CMI where it is converted back to the original 1942.2 MHz. This is the path for the downstream frequency translation.

In an upstream path (CMI to the base station) the conversion works exactly the same, only in the reverse. A CMI receives a portable's RF energy at 1862.2 MHz from two (space diversity) separate receive antennas. Antenna A's RF energy is translated to 20.5

MHz and antenna B's energy is translated to 23.5 MHz. The RF energy is delivered back to the head end using the cable plant and is converted to 1862.2 MHz by the HIC.

The CMI is a low power device with a one watt power amplifier. Since it is only located 23 feet above the ground, it has a very small coverage area (less than one-half mile range for GSM, larger for CDMA).

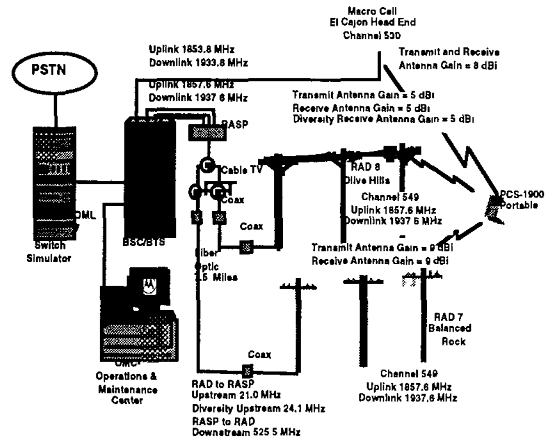

Figure 5.

For the CMI system to cover an area as large as a macrocell, as shown in Figure 5, multiple CMIs are simulcast from a single HIC and base station. From the base station's point of view, the RF energy is sent to only one antenna and its receiver is gathering RF energy from only one antenna (two if spatial diversity is employed). The RF transport system uses multiple CMIs (from four to 10) to simulcast and sum RF energy at each CMI to simulate a macrocell sector. In total, the CMI/HIC system is transparent to the radio system and acts as a distributed antenna array with cable friendly frequency conversions.

Baseband Transport

The second technique to use the cable plant for wireless distribution is baseband transport. Baseband transport uses the cable plant to distribute base band (DS0 level) information through the cable plant.

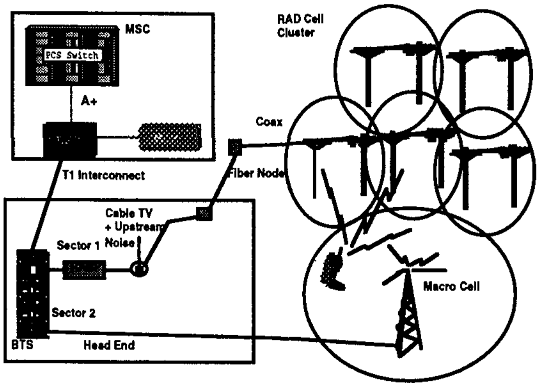

Figure 6.

As shown in Figure 6, it connects the CBSC to the BTS. Instead of using microwave or leased T1s to interconnect all the cells to the CBSC, the cable plant is used. The key benefit of this technique is that the cable plant is already in place and ready to provide this distribution. The CBSC would be located at the headend and the T1 is converted by a cable modem to a channel on the cable plant as shown in Figure 7.

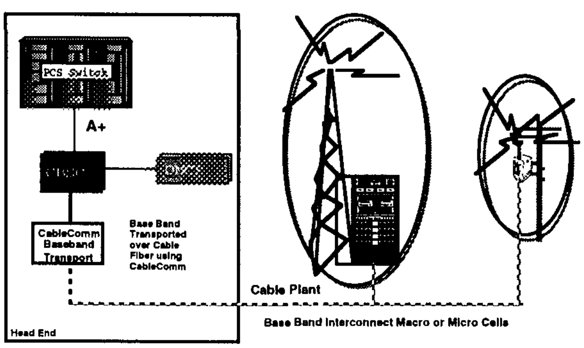

Figure 7.

The cable plant distributes this baseband information to the cell site location. The cable modem retranslates this data to a T1 format that can interconnect to the base station. Motorola has developed its CableComm™ product to meet this interface. CableComm™ can support up to 28 traffic channels in 600 kHz of cable bandwidth.

The trend in the wireless industry continues toward small self-contained microcells. These microcells typically weigh between 40 and 150 pounds and can support from 200 to 500 subscribers. The key advantage to microcells is that they can be located in various environments: top of bill-boards, top of buildings, in buildings and on telephone poles. The cable strand may support up to 60 or 70 pounds. At this weights and coverage area, a microcell coupled with the extensive existing cable plant creates an eloquent service solution for coverage, capacity and backhaul.

The difference between RF transport using CMIs and baseband transport using microcells is illustrated in Table 2.

Table 2. Comparison Summary of RF and Baseband Transport

Issue	**RF transport**	**Baseband Transport**
Number of Radiators	Multiple CMIs simulcasting a single carrier	Single Microcell
Cable Plant noise	Reduces the coverage of the CMI	No effect on the air interface
Location of the base station	Headend	Cable Plant
Cable Spectrum Required	2 to 4 MHz	600 kHz
Number of CMIs or Microcell per Macrocell coverage	10 to 30	5 to 10

BENEFITS OF INTEGRATED HFC AND WIRELESS NETWORKS

Recognizing that approximately 80 percent of a wireless network is the radio system, integrating HFC and wireless networks can provide many competitive advantages for the operator. First economic models have shown that CMI/HIC deployment is potentially one-half the cost of a macrocell deployment on a cost per square mile basis. Cable based microcells may be even less expensive, approaching one-quarter cost of a macrocell deployment on a per subscriber basis. The cost savings are the result of removing the imbedded costs associated with towers, transmission line, power systems, shelters and site improvements.

Beyond one time deployment cost savings, HFC - wireless integration provides continuous operational cost savings by using the HFC network leased lines, land lease improvements are avoided. This issue becomes even more critical with the PCS or 1900 MHz wireless operators. At 1900 MHz, a system will require up to two or three times the number of cells for coverage versus a similar 800 MHz deployment. Additionally, an operator has the opportunity to more fully utilize an existing cable maintenance staff for both HFC and wireless tasks.

Yet another benefit to HFC based wireless system deployment is the potential for a radically lower time required for site deployment. This belief is derived from HFC network ready availability for backhaul along with the absence of zoning/site approval, coupled with HFC operator's right of way access for in-building systems. Compounding these advantages is the relatively short time required to commission a CMI or cable based microcell, on the order of one hour.

Last, and potentially most important of all, is the opportunity to unlock the hidden asset value in the HFC network by demonstrating its versatility and value for wireless. Under analysis, one would expect that by owning a more valuable asset, the stock value of the owner would be positively impacted.

ISSUES ASSOCIATED WITH HFC DEPLOYMENT

As commented previously, Motorola has conducted field trials with both GSM and CDMA CMI/HIC as well as baseband transport. This coupled with Motorola's extensive history as a wireless infrastructure and subscriber unit manufacturer provides Motorola with the broadest view of the issues associated with HFC integration with wireless telephony.

These extensive trials have validated both Motorola's theoretical analysis and system simulations regarding the limits and viability of specific technologies for use in HFC networks. Depending on the particular technology chosen for wireless service, there are significant issues that must be addressed for HFC system deployment. In summary, our trials have demonstrated that these issues are substantially more difficult for GSM CMI/HIC deployments versus CDMA CMI/HIC or cable based microcells with baseband backhaul.

RF Transport Issues (CMI/HIC)

The issues associated with GSM CMI/HIC are fundamental to the cable plant and the GSM air interface. These issues can be summarized under the following four broad categories.

- Dynamic Range
- Noise Summing
- Fiber Node Differential
- Powering

Although other TDMA based air interfaces have not been examined in field trials by Motorola, one would expect that these technologies (IS-54 and IS-136) would deliver similar results as the trialed GSM air interface.

Dynamic Range

Depending on the network usage and configuration the level of ingress or noise becomes problematic. The wireless signal must overcome the noise level if the signal is to be detected at the base station. Effectively, the noise level or ingress in the HFC network reduces the sensitivity of the system. One option to address this issue is to insert gain in the CMI to increase the sensitivity of the unit. Unfortunately, the use of this option is limited on the upper level by the requirement that the upstream lasers not be overdriven to saturation. Upstream laser saturation would interrupt not only the wireless signal but also all video service. Obviously this is not an acceptable condition.

Exacerbating the limited dynamic range is what TDMA based GSM originates at full power (1 watt). This creates the situation were a subscriber located directly next to a CMI would saturate an upstream laser. Conversely, CDMA originates at minimum power and allows for a larger gain in the CMI. This minimizes the concern of a call origination occurring too close to a CMI and interrupting upstream services.

Noise Summing

The issue of noise summing is similar to the law of diminishing returns. To elaborate, with the introduction of each CMI, the overall noise level of the cable plant is increased and therefore requires additional CMIs to overcome the increased noise floor. To minimize this effect, it is important to decrease the number of CMIs as much as possible. Effectively, the coverage advantage delivered by CDMA is magnified by the noise summing condition thus producing substantially more CMIs for GSM versus CDMA.

Fiber Node Differential

During our trials, it has been observed and measured that due to the distance traveled in the HFC network the vast majority of fiber nodes are not within the equalization tolerated in a TDMA based GSM network (16 μsec). The impact of this problem is that some form of equalization circuitry must be calculated and installed in the CMIs prior to a GSM system deployment. Beyond the added complexity in the CMI this issue raises tremendous operational and system planning issues for the operator. Such operational and planning issues include: time, location and skill required for CMI placement; viability of disaster recovery and self healing fiber rings due to the dynamic delay changes; and system growth planning.

Powering

As more centralized power systems are introduced for reliability, it becomes increasingly important to limit the number of CMIs and the collective current draw per fiber node. Beyond the simple economics of requiring more power supplies for more CMIs, it is also important to monitor the network design to insure that maximum current is not reached on any particular power feed. This issue is compounded with the larger number of CMIs required for GSM based system deployments.

Baseband Transport Issues

The issues noted above are less of an impact for baseband transport due to the fact that baseband transport is performed in a known digital format that allows lower power levels, error correction, auto noise tuning and auto-level setting. The primary issues for baseband transport are microcell pricing, security of cell and weight/size versus power output tradeoffs.

HFC NETWORK INTEGRATION PLANS

Motorola is continuing its program of developing cable based microcells with integrated baseband transport as well as additional improvements and system level trials with CDMA CMIs.

SUMMARY

Hybrid Fiber Coax networks continue to proliferate as the chosen architecture for meeting the broadband service requirements of consumers. These HFC networks provide significant cost and time savings for operators wishing to more fully leverage the value of the network to distribute wireless signals. Nonetheless, the technology and approach used to distribute the wireless service play dramatic roles in the operator's competitive cost and time advantage in future operation plans.

Of particular note there remains significant uncertainty and work with regard to TDMA based CMI/HIC deployment. In contrast due largely to the noise immunity and coverage enhancements provided by CDMA's spread spectrum, either CDMA RF or baseband transport appear to be viable and economically attractive solutions for an integrated HFC-wireless system deployment.

ABOUT THE AUTHORS

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Mr. Hammond is a member of Motorola's PCS Core Marketing group within the Pan American Markets Division. During his five year tenure with Motorola Mr. Hammond has held various positions in the engineering, sales and marketing groups. He holds a Bachelor of Science Degree in Electrical Engineering from Purdue University, a Master of Science Degree in Engineering from West Coast University and a Master of Business Administration from The Lake Forest Graduate School of Business. Prior to joining Motorola, Mr. Hammond held positions in missile flight test and engineering with General Dynamics in California.

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Douglas E. Hohulin

Mr. Hohulin has been with Motorola for over seven years and his present role is Business Development Manager. While at Motorola, Mr. Hohulin has been an instrumental technical member of multiple account teams throughout the world. Through these diverse and expansive experiences, Mr. Hohulin has gained extensive real world experience in radio frequency system design and network architecture analysis. Included in Mr. Hohulin's experiences are assignments in Europe, South America and the United States as both a technical expert and sales engineer. Prior to joining Motorola Mr. Hohulin was employed by Magnavox in Ft. Wayne, IN. He holds a Bachelor of Science Degree in Electrical Engineering from Purdue University.

Acronyms

HFC	Hybrid Fiber Coax
GSM	Global Systems for Mobile Communications
CDMA	Code Division Multiple Access
RF	Radio Frequency
TCI	Telecommunications, Inc.
FTTH	Fiber To The Home
FTTC	Fiber To The Curb
FTTN	Fiber To The Neighborhood
CBSC	Centralized Base Station Controller
MSC	Mobile Switching Center
MSO	Multiple System Operators
PSTN	Public Switched Telephone Network
PCS	Personal Communication Services
TDMA	Time Division Multiple Access
RAD/RASP	Remote Antenna Driver/Remote Antenna Signal Processor
CMI/HIC	Cable Microcell Integrator/Headend Interface Converters