Recognizing and Resolving LTE/CATV Interference Issues

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While the expression “4G” has been used to describe a wide variety of next generation cellular technologies, LTE (Long Term Evolution) is by far the most dominant and widely deployed of these technologies. Commercial LTE service is available in over 100 cities throughout the United States, and it is estimated that LTE coverage will be as extensive as so-called “legacy” cellular technologies within two years. Since LTE supports data rates far higher than those of previous cellular technologies, it is also predicted that LTE will be widely used as a primary Internet access technology in many areas, replacing or supplementing such existing last-mile technologies as DSL and cable modems.

LTE differs from previous cellular technologies in a number of ways, primarily in terms of frequency allocations, bandwidths, and modulation types. This has important ramifications for operators of cable networks with regards to the possibility of both ingress and egress interference. Reports of both types of interference have already been received from both cellular carriers as well as cable operators. The number and severity of these incidents is expected to increase as LTE becomes more widely deployed. An understanding of LTE technology and the means by which LTE-related interference can be identified, localized, and resolved is critical for the efficient operation of both cellular and cable networks.
Pre-LTE Cellular Technology in the United States

Prior to the deployment of LTE, there were three major radio access technologies used by cellular service providers in the United States: GSM and WCDMA (AT&T, T-Mobile), and CDMA2000 (Verizon, Sprint). Variants or extensions of these include technologies such as HSDPA, HSUPA, HSPA+ (extension to WCDMA) and 1xEV-DO (extension to CDMA2000). These technologies are frequency-independent, that is, they can be operated in any available frequency range. The ITU-T has defined cellular “bands” that specify the frequencies used by cellular carriers. The downlink/uplink frequencies generally used in the United States for each cellular technology are:

<table>
<thead>
<tr>
<th>Common name</th>
<th>Uplink</th>
<th>Downlink</th>
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<tbody>
<tr>
<td>GSM/CDMA/WCDMA850</td>
<td>869-894 MHz</td>
<td>824-849 MHz</td>
</tr>
<tr>
<td>GSM900</td>
<td>880-915 MHz</td>
<td>925-960 MHz</td>
</tr>
<tr>
<td>GSM1800</td>
<td>1710-1785 MHz</td>
<td>1805-1880 MHz</td>
</tr>
<tr>
<td>GSM/CDMA1900</td>
<td>1850-1910 MHz</td>
<td>1930-1990 MHz</td>
</tr>
<tr>
<td>WCDMA2100 (AWS)</td>
<td>1710-1755 MHz</td>
<td>2110-2170 MHz</td>
</tr>
</tbody>
</table>

Commonly used cellular bands in the United States

Note that not all bands are used in all geographical markets.

It is important to observe that these frequency bands generally lie either at or above the upper frequency ranges used in most modern cable networks. The 850 MHz and 900 MHz bands do however overlap with frequencies used by cable operators who have extended their RF plant to 1 GHz. Aside from these bands, relatively little frequency overlap occurs between the two systems in terms of frequency use, therefore the possibility of either ingress or egress interference has previously been relatively low and easily managed.

Overview of LTE

In the downlink, LTE signals use OFDMA (orthogonal frequency division multiple access) with QPSK, 16QAM, and 64QAM constellations. In the uplink, SC-FDMA (single carrier – frequency division multiple access) is used with QPSK and 16QAM constellations. Although the LTE standards allow for flexible bandwidths of 1.25 MHz, 3 MHz, 5 MHz, 10 MHz, and 20 MHz, cellular service providers in the United States are primarily deploying 5 MHz and 10 MHz LTE networks. LTE deployments in the United States are also FDD (frequency-division duplex), meaning there is a paired downlink and uplink allocation.

Bandwidth in LTE networks is allocated in the form of so-called “resource blocks” in order to allow this bandwidth to be shared among multiple users. A resource block can be described as a set of subcarriers and OFDM symbols. In the case of a 10 MHz signal, there are 50 resource blocks that can be allocated. Resource block allocation is important because studies have shown a correlation between resource block allocations and ingress interference levels in cable networks (see below).

The majority of LTE deployments in the United States are currently taking place in two frequency bands: Band 13 (DL 746-756 MHz, UL 777-787 MHz) for Verizon and Band 17 (DL 734-746 MHz, UL 704-716 MHz) for AT&T. This means that for 860 and 1000 MHz cable plants, LTE signals are within the operating frequencies used by the cable operators.
Why LTE is Different

Unlike much of the previous cellular allocations in the United States, the frequencies used for initial deployment of LTE in the United States are in the so-called 700 MHz band (698-806 MHz). This is important because these frequencies overlap almost completely with all 750 MHz and greater cable systems. Propagation and attenuation characteristics of 700 MHz signals are also very different from cellular signals at higher frequencies: lower frequency signals tend to travel further and be less strongly attenuated by structures, etc., than higher frequency signals.

The use of OFDM in the downlink means that LTE signals also have a higher potential power spectral density than other cellular technologies. This happens when fewer resource blocks are allocated and the total signal power is divided among fewer subcarriers. This in turn can lead to a higher probability of ingress interference as the energy is concentrated in a smaller portion of the allocated bandwidth. Especially in the case of the LTE uplink, it is highly unlikely that all resource blocks will be allocated at the same time.

2G and 3G technologies (GSM, CDMA2K, WCDMA) were originally designed primarily to support voice communications. In contrast, the main motivation behind the development of LTE is to provide high-speed data communications. The traffic distributions of voice and data traffic are very different, and it is expected that an LTE device used for primary Internet access (as opposed to using cable or DSL), especially in the case of video streaming will have a much higher percentage utilization and therefore a greater probability of generating interference or longer periods during which it is generating interference.

While LTE deployments are currently limited to the 700 MHz bands in the United States, plans have been proposed for vacating broadcasters from OTA channels 31-51 (572-698 MHz) and auctioning of this spectrum to make room for new cellular services. Although it is impossible to predict who the winners of these auctions would be, it is reasonable to assume that a significant part of this spectrum might be purchased by cellular service providers, who would likely deploy LTE in these additional bands, that is, at frequencies even lower than the current 700 MHz deployments.

Ingress Interference

Most of the ingress interference studies published to date have been carried out by European organizations. Although the frequencies currently used for LTE in Europe and the United States are different (800 MHz vs. 700 MHz), the results of these studies are still relevant. Despite that fact that interference to STBs has received the most attention, at least one study [Cable Europe Labs] has shown cable modems to be highly susceptible to even very low LTE emission levels.

Several studies [Cobham, Agentschap] have demonstrated the ability of LTE user equipment (UE) to create significant interference to STBs in the form of both picture and data failure, usually with a UE/STB separation of ~1 meter. One study [ANGA] even showed massive STB interference with a separation of 3 meters and a 15 cm steel-reinforced concrete wall between STB and UE. This implies that LTE uplink signals can cause interference even in neighboring apartments or buildings.

Although the majority of tests were concentrated on LTE UEs (uplink), these results are also applicable in the case where the STB is in relatively close proximity to an LTE eNB (base station) [Cable Europe Labs]. Another factor that is likely to be important is the deployment of femtocells or in-building systems. Although these transmitters have much lower power than a standard, tower-type LTE base station, their proximity to consumer devices is much greater. In addition, the attenuation/shielding provided by a structure (base station is normally outdoors) is not present in the case of femtocells or in-building systems. However one potential benefit of femtocells or in-building systems is that the UE would usually be transmitting at a lower power level.

Ingress interference can result from imperfections in the cable plant and connectors, but STB and television equipment design was found to be the largest differentiating factor in determining susceptibility of STBs to LTE ingress interference: most frequently the issue was direct pickup caused by insufficient shielding of the equipment. Neither a lack of sufficient cable shielding effectiveness nor the presence of poorly or un-terminated connectors were listed as significant factors in any of the studies mentioned above, although this certainly does not rule out the possibility of these factors being potential issues.
Egress Interference

Traditionally, the most serious issues involving leakage (egress interference) from a cable network involved egress into the VHF aeronautical band (108-139 MHz). The majority of egress testing taking place today is performed at these frequencies, e.g. by injecting a narrowband signal into the cable system (or using an existing analog TV channel in that frequency range) that also produces a relatively narrowband carrier, and monitoring for egress at this frequency. Although this is an acceptable test for aeronautical frequencies, its applicability in testing for egress from broadband signals at higher frequencies (i.e. 700 MHz) such as QAM carriers, or over a wider frequency range (100 MHz) is problematic due to the lower power spectral density of the cable signal and the difficulty of injecting narrowband carriers between QAM signals.

Conventional leakage detection systems are generally not able to detect digital (QAM) cable signals due to their broadband nature and limited total power in the narrow filter bandwidths of conventional leakage detectors. In fact, many conventional units cannot even receive signals in the 700 MHz band at all. The only way for cable operators to detect these signals is by using a monitoring receiver/spectrum analyzer with a suitable antenna (with filters/preamplifiers as needed) or by turning off a QAM carrier in that band and temporarily injecting a narrow band carrier. This methodology is problematic for logistical and capacity reasons. It requires significant coordination between headend and field techs, which significantly reduces the ease of making the measurements. [Hranac].

With regards to testing the shielding effectiveness of cables and connectors, current measurement procedures for the shielding effectiveness of coaxial cable (such as ANSI/SCTE 48-3-2004) only give a composite value for the entire frequency range (5-1002 MHz), not curves which show shielding effectiveness vs. frequency. F-connectors are a major potential cause of egress issues: they are often low-cost and craft-sensitive (or customer-installed). Although ANSI/SCTE 123-2011 states that the shielding effectiveness for male “F” feedthrough connectors should have the same shielding performance as unspliced cables, this type of performance is unlikely in practice. In fact, some studies have indicated that the shielding effectiveness of F-connectors falls off rapidly at higher frequencies: > 95 dB at 300 MHz but only 70 dB at 1 GHz. [Motorola]. In other words, the shielding of F-connectors at 1 GHz is 25 dB worse than at 300 MHz. Loose or damaged hardline connectors, insufficiently shielded splitters, switches, amplifiers, as well as unterminated outlets are common egress sources. It should be borne in mind that any egress locations are potential ingress locations as well.

Effects of Interference

There are also significant differences between the effects of interference in the aeronautical band and 700 MHz LTE bands. For the most part, signals in the aeronautical bands are amplitude-modulated voice signals used for communication between/among aircraft and ground stations. Interference to these signals usually manifests itself in the form of audible “noise” (e.g. static or buzzing). Although this interference can make communication more difficult, it rarely causes a complete system failure. This type of interference is also recognizable by users well before it reaches a level at which communication becomes impossible. On the other hand, digitally-modulated LTE signals, possibly operating with higher-order modulation schemes, are much more susceptible to interference. LTE systems using 64QAM require a SNR as much as 20 dB higher than legacy systems (GSM, CDMA2K, WCDMA). The effects of interference in these types of systems are also very non-linear. Increasing interference levels may not become noticeable until system performance degrades rapidly or fails altogether – the so-called “cliff effect.”
How Cellular Carriers Approach Interference Hunting

Cellular carriers have a great deal of experience in locating, identifying, and resolving interference issues in their network. Most commonly the initial indications of interference into their networks are either customer complaints (dropped calls, poor voice quality, poor or no data connectivity, etc.) or statistical information provided from the base stations themselves (e.g. high RSSI – received signal strength indication – often indicating noise). In addition, the cellular carriers routinely perform drive-testing of their network with the goal of optimizing the deployment and configuration of their base stations as well as proactively locating sources of interference.

When problems are detected, interference or leakage hunting is performed using portable spectrum analyzers or, more frequently, specialized monitoring receivers that are optimized for detecting and resolving interference issues. While previous leakage detection approaches used in the cable industry often employed dipole antennas, these antennas lack sufficient antenna gain to pull wideband QAM signals up out of the receiver noise floor for detection. Hence vehicle-mounted and hand-held directional antennas (such as the one shown in the figure above) are increasingly used in conjunction with GPS and mapping software to determine the actual physical location of the interference source. Once the interference source is identified and localized, the cellular carriers either work with the owners of the interfering source to resolve the issue or, when necessary, involve the enforcement division of the FCC. It is important to keep in mind that the spectrum owned by the cellular carriers is a very expensive resource that cannot simply be moved or reassigned in the event of interference: cellular carriers aggressively pursue any and all interference which affects the proper operation of their networks. In fact, it is not uncommon for competitors in the cellular industry to work together in the field to investigate interference issues to one or both of their networks.

Measuring Interference

Traditionally most cable egress testing involved making measurements at frequencies (or most commonly at a single frequency) in the VHF aeronautical band, using both local field strength measurements and annual fly-overs. FCC requirements also mandate “substantially covering the plant every three months.” With regards to leakage, FCC 47 C.F.R. §76.605(a)12 specifies the following limits by frequency range:

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Limits</th>
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<tbody>
<tr>
<td>54 MHz &lt; f &lt; 216 MHz</td>
<td>20 μV/m @ 3 meters</td>
</tr>
<tr>
<td>f &gt; 216 MHz (or f &lt; 54 MHz)</td>
<td>15 μV/m @ 30 meters</td>
</tr>
</tbody>
</table>

Acceptable egress limits as per FCC 47 C.F.R. §76.605(a)12

The previous (almost exclusive) focus on egress into the relatively narrow spectral area of VHF airband frequencies was understandable given the potential disruption to aircraft communications. In fact, almost all FCC enforcement actions involving cable egress have been for leakage at VHF aeronautical frequencies.

Even though cable egress may be below the limits above, any measurable level of interfering signals above the ambient noise floor can unfortunately be cause for concern among the cellular network operators. This is particularly true in the uplink band as the user equipment (phones, data cards, etc.) has a much lower transmit power than the downlink signal (base station). Even if the nominal/regulatory limits are adhered to, it should be remembered that any measurable leakage into spectrum licensed to a cellular network operator may be significant enough to cause interference to users of this band.
Observations from Field Testing

Egress interference into the 700 MHz band from both customer-owned and cable operator-owned equipment has been a cause for concern in numerous geographical areas around the United States.

Reports of egress interference affecting 700 MHz LTE deployments have been increasing since the early part of 2011. Conversations with RF engineers in the cellular industry indicate that cable interference into the 700 MHz band has now become one of their most serious issues. In one instance a cellular service provider reported literally hundreds of leaks within a single metropolitan area. Experts from the cable industry have also independently investigated and confirmed egress from cable in the 700 MHz band [Hranac]. The author’s own investigations of outdoor cable enclosures (pedestals, etc.) have shown that measurable levels of leakage are coming from a significant number of these enclosures, often with no outward indication (e.g. damage to the enclosure, etc.) that would indicate that such leaks are occurring.

Field testing has also demonstrated that in addition to the simple detection of egress and determination of the rough location where egress is occurring, resolving egress issues may require very precise (< 1 inch) location of the egress point (i.e. a faulty connection). Wideband directional antennas and/or near-field probes capable of sensing RF at a wide range of levels and frequencies are an indispensable element in these activities.

Common physical defects responsible for egress include ring cracks in the coaxial cables, damage from chewing/gnawing by animals, loose covers, loose hardline connectors, repeater issues (e.g. faulty AGC), etc. Connections and alterations made by persons engaged in cable theft have also been reported as a serious source of problems: improperly spliced cables, poor-quality materials, etc. Fortunately, the tools and methods currently in use for resolving physical defects responsible for VHF airband leakage should be sufficient for resolving 700 MHz leakage. The biggest challenge is ensuring that these higher-frequency, digitally-modulated egress signals can be detected and localized in a precise and effective manner.

It is important to reiterate that several industry groups are proposing to the FCC that over-the-air TV channels 31-51 be “voluntarily” vacated in order to free up approximately 120 MHz of spectrum as part of the government’s National Broadband Plan [CIA/CTIA]. This frequency range (572-698 MHz) is likely to be auctioned off to cellular carriers for data services (LTE or similar). The result of this spectrum “refarming” would be an even greater overlap between the frequencies used in cable and cellular systems, creating even greater potential amounts of ingress/egress interference between these two infrastructures. Egress from cable into cellular bands and ingress into cable systems is likely to become a larger and even more widespread issue in the future.

Above: A comparison of two over-the-air field measurements of cable egress into the 700 MHz cellular bands. The top measurement shows no cable egress, whereas there is substantial egress in the bottom measurement. Note the egress of the 6 MHz cable channels occurs across almost the entire range of 700-800 MHz. With the exception of the AT&T and Verizon downlink signals, all of the other non-narrowband carriers shown in the spectrum and waterfall views are CATV egress from the enclosure shown in the field testing picture.

A field probe designed for measuring signals in the 700 MHz band [Hranac]
Conclusion

Although ingress and egress are not new issues in cable engineering, the deployment of LTE networks in the 700 MHz band represents a new challenge for engineers in both the cable and cellular industries. Ingress interference can be most effectively mitigated by better equipment (STB/modem) design and proper installation and maintenance of outdoor and indoor cable plant. Egress interference may have a substantial impact on the operation of LTE services in licensed 700 MHz spectrum and has both technical as well as regulatory consequences. Previous techniques and tools used to measure egress at a single narrowband frequency in the VHF aeronautical band have shown themselves to be insufficient for diagnosing or locating issues due to broadband waveforms in the 700 MHz band, although the mitigation methods for resolving egress remain the same for both frequency ranges. An important first step is improving awareness of these issues in the cable and cellular engineering communities, thereby enabling an efficient and proactive approach to avoiding both ingress and egress interference in the 700 MHz LTE bands.

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[Cobham] Field tests investigating the potential interference into Cable TV from LTE deployment in the 800 MHz band. S. Munday and I Parker. Cobham Technical Services, Report Number 2010-0792, December 2010.

[Hranac] Correspondence with Ron Hranac, Technical Leader, Cisco Systems (rhranacj@cisco.com).


List of Abbreviations

AGC: automatic gain control
AM: amplitude modulation
AWS: advanced wireless services
CDMA: code division multiple access
dB: decibel
eNB: enhanced node B
EV-DO: evolution data-only
FCC: Federal Communications Commission
FDD: frequency division duplex
GHz: gigahertz
GPS: Global positioning system
GSM: group spécial mobile / global system for mobile communications
HSDPA: high-speed downlink packet access
HSPA: high-speed packet access
HSUPA: high-speed uplink packet access
ITU-T: International Telecommunications Union
LTE: Long Term Evaluation
MHz: megahertz
OFDM: orthogonal frequency division multiplexing
OFDMA: orthogonal frequency division multiple access
OTA: over the air
QAM: quadrature amplitude modulation
QPSK: quadrature phase-shift keying
RSSI: received signal strength indicator
SC-FDMA: single carrier frequency division multiple access
SNR: signal-to-noise ratio
STB: set-top box
UE: user equipment
VHF: very high frequency
WCDMA: wideband code division multiple access
I Wideband analysis covering the entire cable TV spectrum, including MoCA
I Coverage of return path and forward path
I Detects all forms of ingress including that from LTE/4G
I No headend equipment required
I Real-time FFT analysis is faster than any spectrum analyzer
I Handheld and battery operated
I Direction finding capability
I Built-in SD card for recording
I Built-in tone generator for measuring signal strength
I Waterfall display for detecting intermittent signals of all types
I Display easily viewable in direct sunlight

Already being used by wireless carriers nationwide.

To read more about this topic, please visit www.rohde-schwarz-av.com/interference.php