On the Challenges of Mutual Interference between Cable Television Networks and Mobile Fixed Communication Networks in the Digital Dividend Bands

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Abstract—**Recently, the issue of monitoring and repairing leakage from cable television networks have re-emerged, particularly after the International Telecommunication Union released a part of the ultra-high frequency spectrum to mobile broadband services. The newly allocated spectrum, known as the digital dividend bands, was traditionally used throughout Europe for digital TV broadcasting. The emerging problem is the mutual interference between the new frequency spectrum utilized by the Mobile/Fixed Communication Networks and the band used by cable TV providers to offer their services. This article is a brief overview and a starting point for extensive research in this area. We started with a simple description of the cable television system and mobile/fixed communication networks focusing on the aspects associated with ingress and egress interference issues. We also discussed the approaches for detecting and measuring mutual interference and reviewed the relevant literature. This article is concluded with some proposed measures for reducing or mitigating mutual interference.**

Index Terms—**MFCN, LTE/5G, Cable TV, ingress/egress interference, digital dividend bands.**

I. INTRODUCTION

The monitoring and repairing leakage from cable networks operating in the Very High Frequency (VHF) band have been a priority for cable TV providers for decades. However, in the last several years, the signals sent over the cable TV system have occupied nearly the Ultra High Frequency (UHF) spectrum to offer more channels to cable TV users [1]. Many other vital services are operating in the UHF band, such as personal radio services, Public Protection and Disaster Relief (PPDR) services, government communication systems, and air navigation systems [2]. Furthermore, to address the increasing demand for frequencies suited for the implementation of mobile broadband services, the International Telecommunication Union (ITU) has reallocated part of the UHF spectrum range extending from 694 MHz to 862 MHz for Mobile/Fixed Communication Networks (MFCN), particularly for 4G/5G networks [2], [3], [4]. The new bands were allocated in two-phase: the first digital dividend (known as the 800 MHz band) and the second digital dividend (known as the 700 MHz band). Moreover, there has recently been a demand for more of the current UHF television broadcasting spectrum to be reallocated for MFCN services. Thus, the emerging problem is the mutual interference between the frequency spectrum used in MFCN, PPDR, and the spectrum used by cable TV operators to provide their services. Figure 1 outlines that the 700 MHz band (694-790 MHz spectrum) agreement in Hungary is shared by three cellular companies (mobile operators) and public safety agencies [5], [6]. Cable TV systems use the adjacent 470-694 MHz range. The two systems are theoretically independent, but in practice, the cable TV band's higher channels overlap with the communication channels where MFCN is broadcast and vice versa.

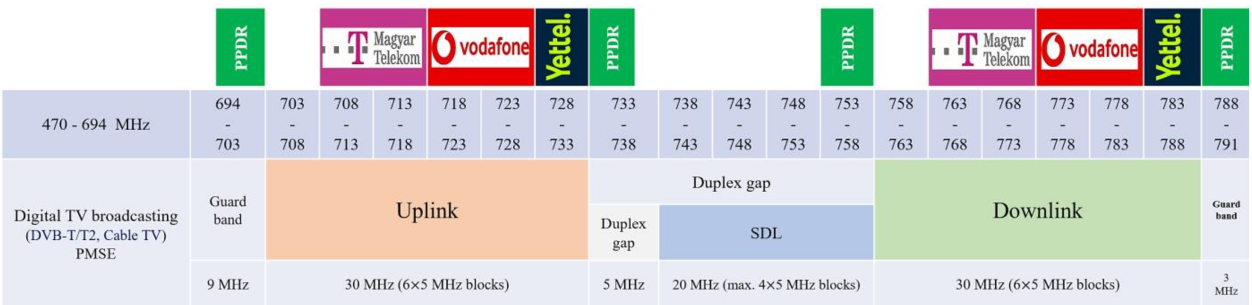

Fig. 1. 700 MHz frequency band: Rights of Use in Hungary

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A cable TV system is characterized as a closed system that transmits signals on frequencies commonly utilized for multiple purposes in air broadcast environments. However, signals may leak out/into the cable network under certain conditions, causing mutual interference between over-the-air users and cable TV transmission, known as egress/ingress interference [1]. Figure 2 shows the general scenario of mutual interference between the cable TV system and MFCN.

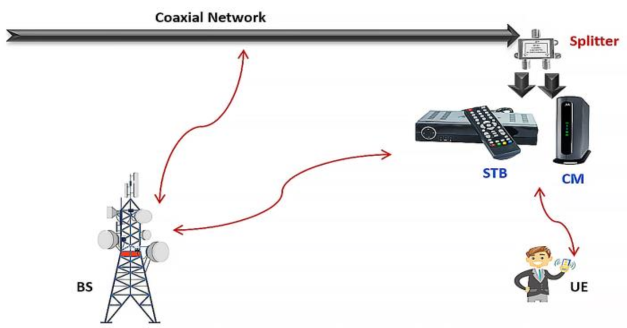

Fig. 2. General scenario of mutual interference between cable TV system and MFCN

Since frequencies in the 700 MHz and 800 MHz bands have been licensed to MFCN, spectrum regulators and public interest management must guarantee that out-of-band interference caused by cable signal leakage into authorized users of the spectrum is avoided. In this regard, the Society of Cable Telecommunications Engineers (SCTE) has issued several technical standards for cable networks. SCTE requires cable television service providers to adhere to certain signal leakage restrictions. TABLE I shows acceptable signal leakage limits as per SCTE [1], [7]:

TABLE I
ACCEPTABLE SIGNAL LEAKAGE LIMITS AS PER SCTE [1], [7]

Frequencies	Limits of signal leakage	Distance (in meters)
216 MHz < Analog signals ≤ 54 MHz	**15** $\mu V/m$	**30**
216 MHz < Digital signals ≤ 54 MHz	**13.1** $\mu V/m$	**30**
216 MHz ≥ Analog signals > 54 MHz	**20** $\mu V/m$	**3**
216 MHz ≥ Digital signals > 54 MHz	**17.4** $\mu V/m$	**3**

Over the last years, numerous field studies, papers, conferences, and symposia have been presented on ingress/egress interference issues in cable and wireless communities. Our article addresses the emerging challenges in mutual interference between cable TV systems and MFCN operating in the digital dividend bands to ensure the electromagnetic compatibility of both systems.

The rest of the article is arranged as follows: Section II presents a brief overview of cable TV system structure, and MFCNs with indicting its properties related to the mutual interference. The sources, effects, and indicators of the two main types of mutual interference are presented in section III. Section IV is devoted to understanding how ingress and egress interference is detected, located, and measured, as well as reviewing the relevant literature. Section VI provides measures that can be taken to reduce or mitigate mutual interference. This paper is concluded with section V.

II. OVERVIEW OF CABLE TV SYSTEM, AND MFCN

A. Cable TV system

A cable television system is a structure that contains a network of closed transmission lines connected with the signal generating, reception, and control hardware needed to deliver cable services. The cable TV system can now provide paying users with three services: television programs, telephone service, and high-speed internet access. Radio Frequency (RF) signals are used to deliver these services across the traditional coaxial cable networks or the Hybrid Fiber-Coaxial (HFC) network [8], [9], [10], [11].

Cable TV providers (Multiple System Operators or MSOs) deliver TV programs service in three tiers or categories, each with its own fee [8], [9]. Cable providers often provide the basic service, which is the most basic level of television programs service. The basic service category provides access to a variety of public, educational, and government television channels that are regulated by the local authority in the nation or city where the cable television operator is licensed to operate. The second category includes all cable system program channels that are not listed in the basic service category. This category may have one or more levels. Furthermore, MSOs provide separate services for each individual channel or program, which is frequently referred to as Pay-Per-View (PPV) service.

Figure 3 shows that the structure of the cable TV system consists of the operator part and the subscriber network part separated by a network termination outlet.

a) The operator part of the network

The cable TV operator constructs and maintains this part to guarantee the supply of a sufficient signal level to all customers' houses. The cable TV operator must follow the requirements defined in the standard IEC 60728-1 to determine the appropriate signal levels and characteristics for the services provided [12].

The MSOs gather all the information required to offer their services. The cable TV systems previously used the DVB-C2 (Digital Video Broadcasting - Cable 2) standard to deliver digital signals through broadband cable networks. DVB-C2 allowed for the most optimal use of cable network resources to generate variable bandwidth signals, which achieved improved spectral efficiency. Also, DVB-C2 was distinguished by its operational flexibility and adaptation to different channel conditions [10], [13].

By the end of the 1990s, MSOs were able to provide real-time communication services, namely Voice over Internet Protocol (VoIP). Later, a Content Distribution Network (CDN) was created to provide advanced multimedia services over a packet-switched network based on the Internet Protocol (IP), namely IPTV system. The IPTV content is delivered to Set-Top

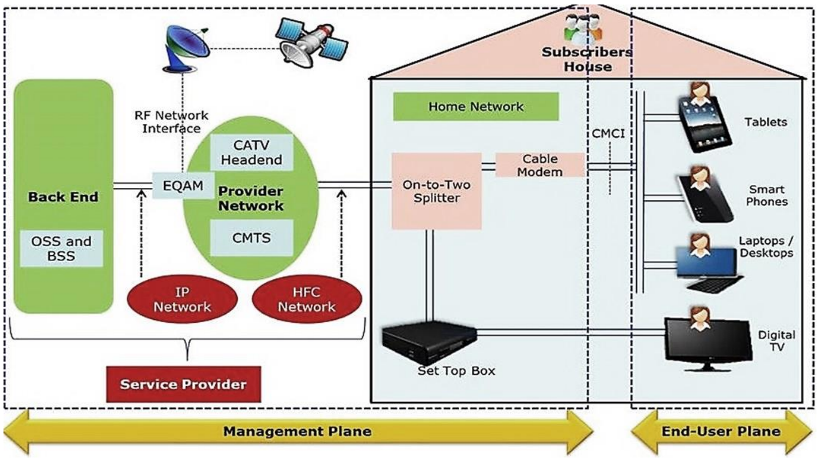

Fig. 3. The structure of cable TV system

Boxes (STBs) through a dedicated and managed network using multicast and initial unicast burst during channel change [14].

In the last few years, Over the Top entertainment (OTT) services have been launched and streamed directly to viewers using modern interactive platforms based on wireless technology. OTT services are privately owned media services that offer subscribers content streaming anywhere and at any time through an open internet and unmanaged network utilizing unicast and simulated multicast (User Datagram Protocol or UDP/Transmission Control Protocol or TCP) routing topology [14]. The evolution of OTT posed new challenges to cable operators that prompted them to develop IPTV service delivery architecture to provide interactive TV services, popular Video on Demand (VoD), and PPV services like YouTube, Netflix, Hulu, Sky Go, Amazon Prime, and others.

As a result, MSOs currently deliver IP video over their network in a controlled environment by providing content libraries and TV services anywhere through the internet as well. MSOs are also an important strategic partner for OTT providers. In order to launch OTT and IPTV, a cable operator needs a management system and a multiplatform player.

The video asset and the associated metadata are typically uploaded by the content producers to terrestrial and satellite transmitters, where they are broadcast to any cable television providers that are authorized to provide that content. The cable TV headend receives these allocated signals, which are then loaded by MSOs into the appropriate VoD distribution servers and made available to customers for a subscription.

On the other hand, MSOs operate with Internet and telephone systems to provide high-speed data transfer over the existing coaxial cable using the Data Over Cable Service Interface Specification (DOCSIS) protocol. The DOCSIS system offers the bi-directional transfer of Internet Protocol (IP) traffic or broadband service between the cable TV headend and subscriber location. The broadband service is supported by a Cable Modem Termination System (CMTS) or a Converged Cable Access Platform (CCAP) at the headend and a cable modem at the subscriber location. A Passive Optical Network (PON) system at the headend and an Optical Networking Unit (ONU) at the subscriber location are additional options for supporting this service [14].

Finally, the DOCSIS and television signals are combined, assigned to the appropriate channels, and then converted to optical signals. The headend connects to the distribution hubs over an all-coaxial or HFC cable network. In a distribution network, the optical nodes convert optical impulses from fibers to electrical RF signals while amplifiers boost weak television signals. The signal is then delivered from the distribution hub to the home network.

b) The subscriber part of the network

The subscriber's coaxial network at home connects with or without home amplifiers with access points or directly to the Set-Top Box (STB) to access TV channels or Cable Modem (CM) to access the Internet. There is a disparity in the home network's quality of components and installations, ranging from high to poor. Low-quality shielding coaxial cables, connectors, and splitters are commonly used or are improperly connected or terminated. As a result, a significant amount of cumulative attenuation of the components may deteriorate the strength and quality of the signal.

B. MFCN (Mobile/Fixed Communications Networks)

The term "MFCN" (Mobile/Fixed Communications Networks) is used in this article to refer to International Mobile Telecommunications (IMT) services and other communications networks operating in the digital dividend bands, namely Long-Term Evolution (LTE), 5G, and public safety services. MFCNs operating in digital dividend bands differ from earlier cellular technology in several aspects, including [15], [16], [17]:

a) Frequency allocations

The frequencies used in the MFCN deployments in the 700/800 MHz ranges are usually at or above the upper-frequency ranges used in most current cable networks. Figure 1 above depicts Hungary's MFCN agreement in the 700 MHz spectrum. It is worth mentioning that transmissions in the low 700 MHz range travel over longer distances but are less attenuated when passing through structures.

b) The modulation schemes

In the MFCN downlink, Orthogonal Frequency-Division Multiple-Access (OFDMA) is used with these modulation schemes: QPSK, 16 QAM, 64 QAM, 256 QAM, and 1024 QAM, whereas in the MFCN uplink, Single Carrier-FDMA (SC-FDMA) is used with QPSK, 16 QAM, and 64 QAM constellations. It is worth mentioning that OFDMA demands a high potential power spectral density, whereas the high modulation level requires a higher SNR and makes the system more vulnerable to interference.

c) Bandwidth and resource block allocation

MFCN use a flexible channel bandwidth. According to [17], MFCN operating in the 700 MHz band can support channel bandwidths of 3, 5, 10, 15, or 20 MHz, while those operating in the 800 MHz band can support channel bandwidths of 5, 10, 15, or 20 MHz. However, most mobile operators primarily use channel bandwidths of 10 and 15 MHz when deploying LTE/5G networks in the digital dividend bands.

The MFCN channel bandwidth is shared among numerous users, whereby a certain number of sub-carriers and OFDM symbols are allocated to each user in the form of a "resource block". For example, 50 resource blocks can be allocated within a 10 MHz channel bandwidth.

There is a correlation between the level of MFCN interference in cable networks and resource block allocations, which may be summarized as follows: As previously stated, utilizing OFDM in the downlink requires a potentially high-power spectral density. Figure 4 illustrates that when just a few resource blocks are allocated within the channel bandwidth, the overall signal strength is focused on a smaller portion of the available bandwidth and distributed over fewer sub-carriers [18]. As a result, this may increase the likelihood of MFCN interfering with cable networks.

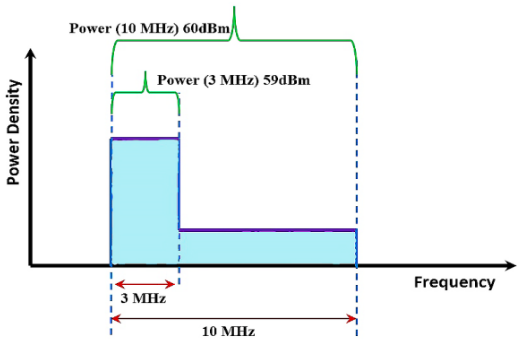

Fig. 4. Example of a correlation between power density and resource blocks allocations in channel bandwidth

III. Ingress/Egress Interference

RF interference happens when an undesired RF signal enters the frequency band used by a service, which negatively affects the quality of service. There are two types of mutual interference between cable TV systems and MFCN.

A. Ingress interference

In this type, unwanted RF signals interfere with cable transmissions [1].

MFCN uplink and downlink signals, impulse noise, and Gaussian white noise are common causes of ingress interference. The interference caused by MFCN is mainly related to how frequency allocations, modulation schemes, and bandwidth are handled. Impulse noise is defined by a short and sharp increase in decibel level, frequently caused by turning on and off electrical gadgets in the home or by loud events in the surrounding environment. Gaussian noise is identified as filtered white noise coming from Customer Premises Equipment (CPE), such as STB, CM, TV set, or other devices used in the cable network. Gaussian noise will lower the Modulation Error Ratio (MER) and Forward Error Correction (FEC) values, causing transmission disruption. Initial indications and effects of ingress interference in cable TV networks are customer complaints, for example, temporary signal loss, poor sound or picture quality, frozen images, intermittent audio, or poor or no data connectivity.

B. Egress interference

Egress interference occurs when unwanted RF signals leak from the cable TV network and interfere with MFCN [1].

Even though cable TV companies comply with SCTE-mandated signal leakage restrictions, the interference probability still exists under certain circumstances. The lack of sufficient shielding, damage to a portion of a closed cable network, or poor installation and maintenance are examples of these circumstances. The leaking signals are QAM signals that may block or degrade desired MFCN communications. MFCN operating in the 700 and 800 MHz bands are particularly vulnerable to interference because the MFCN was designed to achieve high data rates at the cost of lower signal robustness. MFCN uplink signals may have very low amplitude at the base station. Thus, if the leakage point from the cable TV network is near the base station, the QAM signals leaked in the coverage area may be equal to or higher than the MFCN uplink signals. As a result, a user near one of the leakage points might experience dropped or blocked calls and reduced data rates. On the other hand, there will be problems with the MFCN downlink if there are lots of leaks in the coverage area. This would show up as poor coverage for one or more sectors near leakage points, particularly near the edge of the base station coverage area.

Familiar sources of egress interference include poor shielding effectiveness of cable system elements, damaged or loose hardline connectors, unterminated outlets, damage from environmental phenomena, and poor-quality materials. It is worth noting that any egress points are also possible ingress points.

The initial indications and effects of the leakage on MFCN are customer complaints, such as interrupted calls, low voice quality, low data throughput, or even no data connection. Besides, the statistical information offered by the base stations themselves is a significant noise indicator, such as a low Signal-to-Noise Ratio (SNR) or high level of Received Signal Strength Index (RSSI).

On the other hand, both cellular carriers and cable TV providers perform routine tests for early detection of noise and negative impacts, including cable TV providers calculating the

Cumulative Leakage Index (CLI) in a given area and mobile operators performing drive-testing.

IV. Interference hunting approaches and relevant literature review

This section presents the approaches for detecting and measuring ingress and egress interference and reviews the relevant literature.

We can distinguish three main approaches for detecting and measuring leakage from cable TV networks [19]. The simplest and most cost-effective method is injecting a narrow-band carrier at a specific frequency between two adjacent QAM channels and then measuring the leakage at that frequency. The injected carriers have unique signatures for each cable TV provider, so detecting which cable TV network emitted the leaking test signal is feasible, and thus the leakage can be fixed. Using this approach, the leakage field strength can be automatically and continually monitored by installing inexpensive receivers in fleet vehicles owned by companies in the region of the cable TV provider. For instance, leakage detectors may be installed on garbage trucks that service the target area, and the cable TV operator would then get the collected data to analyze and take the necessary action. The second method depends on creating a correlation of QAM signals at the cable system's headend with signals measured in the field. However, this approach requires special equipment and independent data link at both the headend and in the field. The most flexible approach is a spectral analysis using a monitoring receiver and high gain active directional antenna [20]. Using this approach, the equipment can offer a comprehensive snapshot of the leakage signal, yet it must be manually operated by a technician.

TABLE II describes in detail the characteristics and methodology used in the leakage detection methods, including manufacturers of appropriate equipment for each technique as well as relevant reference studies.

In the paper [19], numerous authors worked to establish several detailed and updated operating procedures to mitigate digital QAM signals leakage from cable TV networks. These operational practices included defining the performance metrics to be measured, recommendations for obtaining appropriate equipment and how to calibrate and use them, explaining the requirements for continuous monitoring and maintenance of leakages, and coordinating leakage measurements and then analyzing them for troubleshooting. Several instructions were also provided on what to do when contacting the LTE operator concerning interference.

The Society of Cable Telecommunications Engineers (SCTE) in the USA performed laboratory testing in a controlled environment in two stages [1]. In the first stage, the effect of QAM signal leakage on the LTE downlink was investigated by

TABLE II
CHARACTERISTICS OF LEAKAGE DETECTION APPROACHES

Approaches	Injected carrier method	Correlation Method	Portable spectrum analyzer method
Detection system components	- A signal source "marker" is installed in a headend or hub. - A platform for detecting GPS leaks in fleets. - The handheld detection devices.	- A reference signal that is acquired by connecting to the cable network. - A leakage signal captured using an antenna at a field location. - A correlation detector.	- Portable monitoring receiver. - Active directional high gain antenna.
Methodology	Inject a narrow-band carrier "marker" at a specific frequency between two adjacent QAM channels in the headend and then measure the leakage at that frequency using handheld field detection units that are programmed to detect the corresponding marker signal.	The correlation method determines if there is a correlation between the snapshot of the QAM signal at the headend (or another site in the network) and a leakage signal received at the leaking antenna. The two signals are the same if there is a correlation and the two signals have the same components. In this case, we know that QAM egress is being monitored. The Time Difference of Arrival (TDOA) location technique compares the times of arrival of the two waveforms to locate the source and intensity of the leakage.	The approach consists of two major steps: The first step is to examine the statistical data provided by the MFCN base station, which may indicate a potential leakage issue, such as a low SNR or high RSSI. The next step is to connect a spectrum analyzer to the uplink/downlink antenna test point and check for clear signs of RF interference.
Features	The simplest and most cost-effective method.	This technique considers two crucial factors simultaneously to determine whether a leakage will negatively impact MFCN transmission. The first is the distance and beam path from the leak to the tower. The second is the leak's amplitude at the MFCN transmission frequency.	The most flexible approach that can provide a comprehensive snapshot of the leakage signal.
Manufacturers	CPAT, VIAVI, ComSonics, and Effigis.	ARCOM Digital, and VIAVI.	Rohde & Schwarz, Aaronia AG, Narda, Anritsu, and VIAVI.
Related reference studies	SCTE operational practices [17].	SCTE operational practices [17], ARCOM technical report [19].	SCTE operational practices [17], SCTE technical report [20], In Poland [21].

measuring the CQI and the user equipment data throughput during the test. Besides, numerous parameters have been adjusted for downlink tunings, such as transport block size index, code rate, and block error rate. Then, the QAM signals strength and the error correction level were varied to determine their effect on the downlink. The test results at this stage showed an inverse relationship between the QAM power leakage and the distance between the leak source and the affected receiver. As the distance doubles, the resulting field strength of a leak is decreased by 6 dB, assuming there are no reflections or obstacles in the free-space signal path. In the second stage, the effect of QAM signal leakage on the LTE uplink was studied by measuring the RSSI and the data throughput of the base station. During the test, the QAM signal strength was increased by 6 dB every 15 minutes, and then the data throughput and timestamp were measured at each level. The results indicated that digital QAM signal leakage significantly impacted LTE uplink performance to the point where a low field strength (5 μV/m) at the antenna plane produced interference.

In [21], ARCOM equipment was used by mobile operator "Verizon" to identify QAM signal leakage from cable TV networks. Firstly, the specialists first divided the coverage of each tower into quadrants. When initial indications indicate interference in the quadrant, such as low SNR or high RSSI, they drive out the affected quadrant using an analyzer and monopole antenna. Then, the source of the leakage was isolated using an analyzer and a Yagi antenna. Time Difference of Arrival (TDOA) technology has been used in some cases to locate the leakage in the GPS. According to the obtained results, the average leak per mile was 70% in high frequency only (at 717 MHz), 20% in low frequency only (at the aeronautical band), and 10% in both high and low frequency.

The authors of [22] emphasized the need to monitor leakage in both aeronautical and broadband frequencies. Since field measurements revealed no correlation between the strength of the leakage field and low or high frequencies, leaks might exist in the higher band even if they did not exist in the lower band. In addition, the leakage strength varies depending on the source and mechanism. The researchers developed a program for detecting and repairing cable signal leakage over the air at multiple frequencies, reducing harmful interference, and ensuring the quality of cable TV service.

In Poland [23], the researchers used a monitoring receiver and an active directional antenna to measure leakage from several components of a cable TV network operating at a site. The leakage field strength was first measured at a certain distance from the equipment and employed as a threshold level, and then the leakage field strength was measured near the leaking source. By comparing the level of radiation observed in the field with the maximum levels given by the Federal Communications Commission (FCC), the researchers could determine the critical leak locations at specific frequencies. They concluded that poor initial network installations were responsible for most leakage cases.

The ingress interference and direct pickup noise (impulse noise) are discussed in detail in [24], [25]. The causes, sources, and effects of ingress interference and impulse noise at UHF band were explored in [24]. This report also included many practical measures contributing to rapid detection and mitigation of ingress and impulse interference. The authors of research published in Belgium [25] reported the link between ingress interference and direct pickup noise and their effect on 16 QAM transmission. A setup was designed that emulates the return path in a cable network. The ingress interference was measured using a spectrum analyzer connected to a computer, while an oscilloscope with a high sampling rate was employed to measure the pulse noise. Then, the authors measured the effect of ingress interference and impulse noise on the performance of QAM transmission. The results were displayed in graphs through a developed program on MATLAB software. These diagrams helped cable providers choose appropriate frequencies with ingress interference and direct pickup noise.

In the Netherlands, Dutch Radiocommunications Authority and the University of Twente investigated the interference of the LTE system with the cable television system in the 800 MHz band [26], [27]. The interference probability in overall households was low. They considered two possible scenarios for interference to occur: One, if someone was making a phone call in the 800 MHz band on the same channel used to show a TV program simultaneously. In the second scenario, an interference probability of about 48% will cause the digital TV signal to be distorted if there is co-channeling. However, this percentage varies depending on many factors. They also suggested measures for individual households to reduce the interference probability more, such as using good quality cables, good plugs in the home, and not using the cellphone near cable TV system equipment in the house.

In the United Kingdom [28], the Cobham Technical company investigated potential interference from LTE user equipment operating in the 800 MHz spectrum into most types of STBs and CMs available in the local market. The researchers investigated the following factors: for STBs, they evaluated the quality of the received digital signal using the picture failure standard and the effect of varying the cable signal strength in the STBs and changing the resource block allocations used in the UE signal. For CMs, they used a data failure criterion to assess the quality of the received digital signal. Additionally, they examined the hardware design of most tested STBs and CMs. The results of the tested STBs showed that most of them were affected by interference from the maximum LTE UE power broadcast at a separation distance of 1 meter. However, a 1 dB increase in the cable signal level in the STBs significantly reduced the interference. On the other hand, the partial resource block allocation in the LTE UE signal increased the interference level in the STB. While the results of the tested CMs revealed that all of them were affected by interference from the maximum LTE UE power broadcast at a separation distance of 1 meter. Finally, the hardware design examination revealed that all the evaluated STBs had a metal design with perforations that enabled undesirable signals to pass into the sensitive circuits. The design quality of the examined CMs varied based on their components and materials. The influence of designs was evident in the test findings.

The authors of [29] performed an experimental analysis to cancel interference of a wide 20 MHz LTE signal with cable TV systems in 700 MHz band. A new design was suggested to reduce LTE interference in cable TV transmissions by adapting the phase and amplitude of multi-paths LTE signals in broadband.

In Croatia [30], in-house measurements were performed in a controlled environment to prevent both ingress and egress interference. Firstly, a suitable setup was configured to examine the effect of varying the cable TV system's modulation levels and signal strength. The researchers determined levels of immunity enhancement in the cable TV system interfered by the LTE-uplink signal at 795 MHz when the QAM modulation level decreases from 256 QAM to 64 QAM or when the input power level increases by 10 dB. They found that the increase in input power level was more beneficial. Secondly, they examined the vulnerability of the passive and active elements of the cable TV system to interference. The tested elements were: three different cables, four connector configurations, additional passive elements, and different STBs. The test results were evaluated according to the modulation error ratio (MER in dB) versus cable signal level (dBμV). According to the test findings, the researchers could classify the equipment based on its degree of sensitivity to interference. The critical components were low-shielding cables and connectors, whereas the STB was the most vulnerable to interference.

In Hungary [31], the authors measured the Shielding Effectiveness (SE) of passive cable network components, such as various cables, multi-taps, and line splitters. Additionally, they examined the impact of various factors on the measurement results, such as cases of twisted cables, damaged splitters, and loose taps. The test findings determined that the proper initial cable TV network installation, the employment of high-quality components, and appropriate shielding offer sufficient protection against interference caused by unwanted signals in the broadband. However, some faults that develop over time and produce a rise in harmful interference, such as destroyed or twisted shielding or loose connectors, need continuous maintenance.

Later, the Hungarian authorities carried out internal technical work collaborating with the mobile operator and cable TV provider to avoid harmful interference between the network elements. They determined the minimum required physical distances between the cable TV elements and MFCN-base station and MFCN-user equipment to prevent mutual interference according to modulation level, DOCSIS versions, and the shielding effectiveness of cable TV elements. According to the results of this technical work, the required minimum physical distances to prevent mutual interference between the cable TV system and MFCN increase with the decrease in the shielding effectiveness of cable TV elements and with an increase in the QAM modulation level. However, employing the most recent DOCSIS version decrease the minimum separation distance compared to the prior DOCSIS version, despite using the same QAM modulation level in the previous one.

V. PROCEDURES TO MITIGATE THE MUTUAL INTERFERENCE

The first step in mitigating interference is to create a team that is fully aware of interference issues in both cellular operators and cable TV providers. On the one hand, this team is responsible for proper initial installation and ongoing maintenance, and it is striving to enhance community awareness of interference issues on the other hand. Later in actual practice, if a problem occurs that causes interference, the party responsible for the solution is determined based on the cause, whether it is the cable provider, the cellular company, the device manufacturer, or even the user in some erroneous practices.

As the digital dividend bands are now licensed to the MFCN, leakage from the cable networks to authorized users is forbidden, and cable TV providers may face exorbitant fines from spectrum regulators. Moreover, any leakage points of the cable TV network are potential ingress points causing signal degradation for their subscribers. As a result, cable TV providers must comply with acceptable signal leakage and shielding effectiveness limits as per SCTE, besides continuous monitoring and measuring the cumulative leakage level over time.

In general, resolving radio-signal interference issues necessitates addressing one or more of the following components: an item susceptible to interference, a source of unwanted signal energy, and a propagation path.

The suggested procedures to mitigate the interference concerning the first component that is vulnerable equipment to interference include correcting installation errors of outdoor and indoor cable TV networks, maintaining the shielding effectiveness, and using improved cabling inside the home and STBs/CMs with enhanced immunity.

Regarding the source of noise, we suggest the trade-off between using a specific QAM modulation level and input power level in the cable television system to achieve an acceptable degree of immunity enhancement in the cable TV system while being exposed to MFCN interference. On the other hand, reducing the power levels of MFCN in the adjacent bands is beneficial. Additionally, cable TV providers should consider implementing forward error correction algorithms to improve the system's immunity to interference while the modulation level is upgraded.

Lastly, regarding the propagation path of unwanted signals, one of the recommendations for mitigating mutual interference is to adjust the antenna's gain, tilting, and radiation pattern at the MFCN base station [1]. These factors impact how QAM leak levels affect RSSI and, therefore, the MFCN performance. The electrical or/and mechanical tilt changes the antenna radiation pattern to optimize the performance of the MFCN under certain conditions. Figure 5 displays that the antenna should be oriented vertically, and the radiation pattern should have a narrow width of no more than 15 degrees [1]. Besides, the reduction in antenna gain caused by variations in the vertical antenna pattern near the cellular tower reduces the effect of QAM signal leakage located below the main lobe antenna pattern.

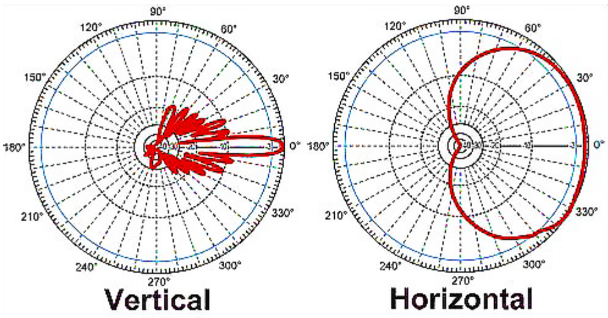

Fig. 5. The radiation pattern and tilting of the antenna

This tuning has the benefit of reducing the influence on the base station while also increasing sensitivity gain by 20 dB or more, considering the difference in effect based on the distance between the leak location and the antenna's main lobe or side lobes [1]. On the other hand, when implementing the Multiple-Input and Multiple-Output (MIMO) system in the base station, spatial multiplexing and diversity technologies will assist limit the impact of cable TV signal leakage.

Although the recommendations mentioned above regarding the propagation path of unwanted signals seem theoretically possible, in practice, they are very challenging for the following reasons: Many other variables might affect the intensity of the leak QAM signal that reaches the MFCN base station, such as physical obstructions (terrain, buildings, trees, etc.). Therefore, it is impractical to utilize fixed guidelines to avoid leakage levels that may interfere with the MFCN base station. On the other hand, those suggestions are not in line with the current practices of mobile operators. Many locations currently do not have MFCN antennas installed on towers, as in the case of microcells, have antennas installed on the sides of buildings or utility poles. In these situations, the MFCN antennas may be near the cable TV infrastructure; thus, even minor QAM leakage might interfere with the MFCN signal.

We also advocate preventative measures to avoid future leakages, such as practical and professional training on proper initial installation, monitoring service quality, periodic maintenance, and collaboration between MFCN operators and cable TV providers.

There is a proposal to provide appropriate instructions to the subscribers to avoid future problems (for example, do not use cellular devices near cable equipment to avoid poor cable TV service quality). Prohibiting the sale of unshielded devices and issuing legal rules regulating customer behavior could also help mitigate the harmful interference of cable TV services and MFCN in digital dividend bands.

VI. Conclusion

This article discussed the emerging challenges in mutual interference between cable TV systems and MFCN operating in the digital dividend bands. We presented the 700 MHz spectrum sharing agreement in Hungary as an example to illustrate this issue.

We started this article by explaining the structure of a cable television system and a brief description of the digital signal transmission process from the operator to the subscribers' homes. Next, we covered all the interference factors related to MFCN operating in digital dividend bands. Then, we outlined the typical sources, influences, and primary indicators of ingress and egress interference for cable TV providers and cellular carriers. Following that, we discussed the methods for detecting and evaluating mutual interferences previously employed in several European nations and the United States, whether in the laboratory or the field. Finally, based on prior research findings, we categorized all measures and procedures that may be used to avoid or mitigate mutual interference according to the three main components: an item susceptible to interference, a source of unwanted signal energy, and a propagation path.

Ultimately, despite progress in raising awareness of potential interference issues in the cable and wireless industries, resolving mutual interference will not be quick or straightforward. However, proactive maintenance and good engineering practices can help.

Moreover, the ITU is currently working on sharing and compatibility studies in the new frequency range 470-694 MHz, implying that more frequencies below 700 MHz would be allocated for mobile broadband services. As a result, MFCN and cable providers will face new challenges due to this new frequency range, emphasizing the significance of addressing ingress and egress issues.

References

[1] Engineering committee and network operations subcommittee, “Technical Report UHF Leakage, Ingress, Direct Pickup”, SCTE Technical Report, The Society of Cable Telecommunications Engineers (SCTE), 209, Exton, PA, USA, 2015, pp. 1–80. [Online]. Available: https://www.scte.org/documents/203/SCTE-209-2015-1575563912519.pdf

[2] International Telecommunication Union (ITU), Geneva, Switzerland. [Online]. Available: https://www.itu.int/

[3] P. Lamy, “Results of the work of the high-level group on the future use of the UHF band (470-790 MHZ)”, Report to the European Commission 1, 2014, pp. 1–34 [Online]. Available: https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=6721

[4] The European Parliament and the council of the European Union, “Decision (EU) 2017/899 of the European Parliament and of the Council of 17 May 2017 on the use of the 470-790 MHz frequency band in the Union”, Strasbourg, France, 2017. pp. 1–7 [Online]. Available: http://data.europa.eu/eli/dec/2017/899/oj

[5] NMHH, “National roadmap for the utilization of the VHF III (174–230 MHz) and the UHF (470–790 MHz) frequency bands; the future of digital broadcasting and mobile broadband frequency use options”, National Media and Infocommunications Authority (NMHH), Budapest, Hungary, published on 20 August 2017, pp. 1–22. [Online]. Available: https://english.nmhh.hu/document/190192/uhf_vhf_3_national_roadmap_eng.pdf

[6] T. I. Unger, “Frequency co-ordination: MFCN Agreements in Hungary; Tasks and Challenges in the Present and for the Future”, National Media and Infocommunications Authority (NMHH), Budapest, Hungary, published on 2 July 2020, pp. 1–27. [Online]. Available: https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2020/Spectrum_EUR_CIS/Tamas%20Unger%20(1).pdf

[7] 76.605 Technical standards, title-47, section CFR § 76.605, Cable Rules | Federal Communications Commission, 2018. [Online]. Available: https://www.ecfr.gov/current/title-47/section-76.605

[8] L. Harte, “Introduction to Cable TV (CATV) Systems, Services, Operation, and Technology”, 3rd edition, Discovery Press, 2017. ISBN: 978-1932813180, [Online]. Available: https://www.amazon.com/Introduction-Cable-CATV-Operation-Technology-ebook/dp/B06XQ7C497

[9] ITU, "The future of cable TV: Trends and implications", International Telecommunication Union (ITU), Geneva, Switzerland, 2018. [Online]. Available: http://handle.itu.int/11.1002/pub/81216af5-en

[10] ETSI Technical Specification, "Digital Video Broadcasting (DVB); Implementation Guidelines for a second-generation digital cable transmission system (DVB-C2)", ETSI TS 102 991 V1.3.1 (2016-01), 2016. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/102900_102999/102991/01.03.01_60/ts_102991v010301p.pdf

[11] L. Chiariglione and C. A. Szabó. "Multimedia Communications: Technologies, Services, Perspectives", Infocommunications Journal, 6(2), 2014, pp. 27–39. [Online]. Available: https://www.chiariglione.org/publications/papers/infocom/Pages%20from%20InfocomJ_2_komplett.pdf

[12] IEC Technical Specification, "Cable networks for television signals, sound signals and interactive services - Part 1: System performance of forward paths", IEC 60728-1: (May-2014), 2014. [Online]. Available: https://cdn.standards.iteh.ai/samples/19970/f1db2762aa2c43e29850d009bb73ade1/IEC-60728-1-2014.pdf

[13] W. Fischer, "Digital Video and Audio Broadcasting Technology. A Practical Engineering Guide", Springer, Fourth Edition, 2020. DOI: 10.1007/978-3-030-32185-7

[14] M. Toy, "Cable Networks, Services, and Management", John Wiley & Sons, Hoboken, New Jersey, 2015. ISBN: 1118837592, 9781118837597, [Online]. Available: https://www.wiley.com/en-ie/Cable+Networks%2C+Services%2C+and+Management-p-9781118837597

[15] CEPT, "To develop harmonised technical conditions for the 694 -790 MHz ('700 MHz') frequency band in the EU for the provision of wireless broadband and other uses in support of EU spectrum policy objectives", CEPT Report 053, 2014. [Online]. Available: https://docdb.cept.org/download/86

[16] ECC, "Harmonised technical conditions for mobile/fixed communications networks (MFCN) in the band 694-790 MHz including a paired frequency arrangement (Frequency Division Duplex 2x30 MHz) and an optional unpaired frequency arrangement (Supplemental Downlink)", ECC Decision (15)01, 2015. [Online]. Available: https://docdb.cept.org/download/1502

[17] ETSI Technical Specification, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 15.9.0 Release 15)", ETSI TS 136 101 V15.9.0 (2020-02), 2020. [Online]. Available: https://https://www.etsi.org/deliver/etsi_ts/136100_136199/136101/15.09.00_60/ts_136101v150900p.pdf

[18] P. Denisowski, "Recognizing and resolving lte/catv interference issues", White Paper, *Rohde and Schwarz*, 2011. [Online]. Available: https://www.mobilewirelesstesting.com/wp-content/uploads/2017/11/LTEInterferenceIssues_WP.pdf

[19] S. Windle, R. Hranac, N. Segura, K. Couch, M. Darragh, G. Tresness, and D. Howard, "Operational Practice for Minimizing Signal Leakage in the UHF Spectrum", *JOURNAL OF NETWORK OPERATIONS*, 2016, pp. 55–78. [Online]. Available: https://www.scte.org/documents/3593/SCTE-ISBE-NOS_Journal_V1N1.pdf

[20] P. Denisowski, "Spectrum Analyzers vs. Monitoring Receivers", *Rohde & Schwarz*, 2017. Online available: https://silo.tips/download/spectrum-analyzers-vs-monitoring-receivers-paul-denisowski-application-engineer

[21] ARCOM digital, "LTE interference and CATV", 2014, pp.1-63 [Online]. Available: https://pdf4pro.com/cdn/lte-interference-and-catv-2f0440.pdf

[22] R. Hranac, G. Tresness, "Another Look at Signal Leakage; The Need to Monitor at Low and High Frequencies", A Technical Paper prepared for the Society of Cable Telecommunications Engineers, *SCTE Cable TEC*, EXPO12, Orlando, USA, 17-19 October 2012, pp. 1–32. [Online]. Available: https://www.arcomdigital.com/wp-content/media/hranac-tresness-scte-white-paper.pdf

[23] M. Sadowski, "Leakages from devices of CATV system", *IFAC-Papers Online*, 51.6, 2018, pp. 490–495. DOI: 10.1016/j.ifacol.2018.07.108

[24] J. Wider, and R. Hranac, "Operational Practice for Identifying, Locating and Mitigating UHF Ingress and Direct Pickup in Cable Networks and Devices", *Journal of network operations*, 2016, pp. 4-26. [Online]. Available: https://www.scte.org/documents/3593/SCTE-ISBE-NOS_Journal_V1N1.pdf

[25] S. Bette, V. Moeyaert, V. Tamgnoue, M. Blondel, P. Mégret, "Comparative analysis of the impact of CATV return path ingress and impulse noises in a 16QAM transmission system", Service d'Electromagnétisme et de Télécommunications, Faculté Polytechnique de Mons, Belgium, 2004, pp. 1–8. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.723.8372&rep=rep1&type=pdf

[26] R. Schiphorst et al., "Analysis of interference to cable television due to mobile usage in the Digital Dividend", Radiocommunications Agency Netherlands, Groningen, Netherlands, 2010, pp. 1–80. [Online]. Available: https://research.utwente.nl/files/5124397/ATEL%20rapport%20kabel%20stoor%20onderzoek%20EN%20DEF%2022072010%20hires.pdf

[27] J. Robijns, and R. Schiphorst. "Interference to cable television due to mobile usage in the Digital Dividend-Analysis", *10th International Symposium on Electromagnetic Compatibility,* IEEE, 2011, pp. 260–265. [Online]. Available: https://ieeexplore.ieee.org/document/6078544

[28] S. Munday, and I. Parker. "Field Tests Investigating the Potential Interference into Cable TV from LTE Deployment in the 800 MHz band", Cobham Technical Services, Report number: 2010-0792, 2010, p. 1–83. [Online]. Available: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/101357/2010-0792_LTE_into_CATV.pdf

[29] J. Chen, G. Wu, X. Si, D. F. Hunter, P. Wensheng, Y. Shen, and S. Shao, "An experimental RF noise cancellation analysis for cable access systems", *IEEE Communications Magazine*, 53(3), 2015, pp. 121–125. DOI: 10.1109/MCOM.2015.7060492

[30] A. Teković, "Performance challenges for LTE deployment in digital dividend in Croatia", Croatia, 2014, pp. 1–44. [Online]. Available: https://www.bib.irb.hr/717201/download/717201.IIR__LTE_in_Digital_Dividend_deployment_challenges_atekovic.pdf

[31] P. Prukner, I. Drotár, M. Liszi, and S. Nagy, "Measurement of the Shielding Effectiveness of Passive Cable Television Elements", *ICEST Conference, Serbia*, 2017, pp. 101–104. [Online]. Available: http://rcvt.tu-sofia.bg/ICEST2017_23.pdf

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