WIMAX LINKS AND OFDM OVERLAY FOR HFC NETWORKS: MOBILITY AND HIGHER US CAPACITY

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Abstract

This article proposes a dual-approach solution to augment the US bandwidth in HFC networks. The solution is based on using OFDM channels over the existing cable plant and WiMAX channels over the air.

The proposed approach not only extends the US bandwidth, but also supports backward compatibility, smooth migration, efficient US bandwidth utilization, DOCSIS® 3.0 US channel bonding, load-balancing, US path redundancy, mobility, and. low cost and optimized implementation.

INTRODUCTION

Recent studies show consistent growth in subscribers' bandwidth caused by continuous offerings of killer applications that require faster data rates. Higher speeds are constantly needed to accommodate the transfer of the bandwidth-intensive and latency-sensitive contents associated with these newly developed applications. Not only is the offered bandwidth increasing in the Downstream (DS) direction, but it is also increasing in the Upstream (US) direction, because many applications depend on the Transport Control Protocol (TCP) for data transmission, where the US and DS bandwidths are tightly related. The US bandwidth is also increasing as a result of more services and applications that send more US traffic such as business services, online gaming, and Peer-to-Peer (P2P) transfers.

Hybrid Fiber Coaxial (HFC) networks have very limited return path bandwidth, which presents a serious challenge to Multiple Service Operators (MSOs) and places them at a competitive disadvantage. This paper proposes a solution to extend the US bandwidth in future HFC networks using two parallel (and complementary) approaches, which are described below and shown in Fig. 1:

1. Orthogonal Frequency Division Multiplexing (OFDM) overlay for the cable.
2. Wireless interoperability for Microwave Access (WiMAX) network over the air.

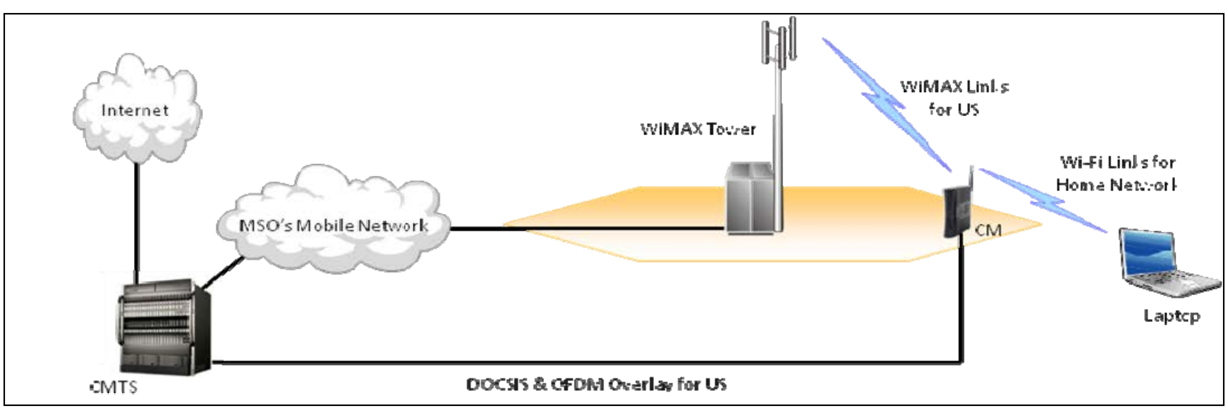

Figure 1. Augmenting the US bandwidth in future HFC networks: OFDM overlay over the cable & WiMAX links over the air

OFDM OVERLAY FOR THE CABLE

The OFDM overlay approach introduces OFDM channels that overlap with the existing conventional DOCSIS® channels but do not interfere with them. This is achieved through the ability of turning on/off the subcarriers that compose the OFDM signal as shown in Fig. 2.

The capability of turning on/off subcarriers is a natural consequence of the architecture of the OFDM signal, which is composed of overlapping and orthogonal subcarriers. In particular, the OFDM signal can be represented as [1] [2]:

$$x(t) = \sum_{i=-\infty}^{\infty} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} a_{k,i} \cdot x_k\left(t - iT_F\right), \quad (1)$$

where $a_{k,i}$ is the complex symbol modulating the k^{th} subcarrier ($x_k(t)$) in the i^{th} OFDM symbol block. The k^{th} subcarrier $x_k(t)$ is expressed as:

$$x_k(t) = \frac{1}{\sqrt{N}} w(t) \cdot e^{j2\pi f_k t}, \quad (2)$$

where $w(t)$ is a unity amplitude rectangular window that is nonzero in the range $0 \le t \le T_F$ and $f_k = k/T_F$ is the k^{th} subcarrier frequency.

The $1/\sqrt{N}$ term is a normalization factor included to ensure that the OFDM signal power is independent of the number of subcarriers.

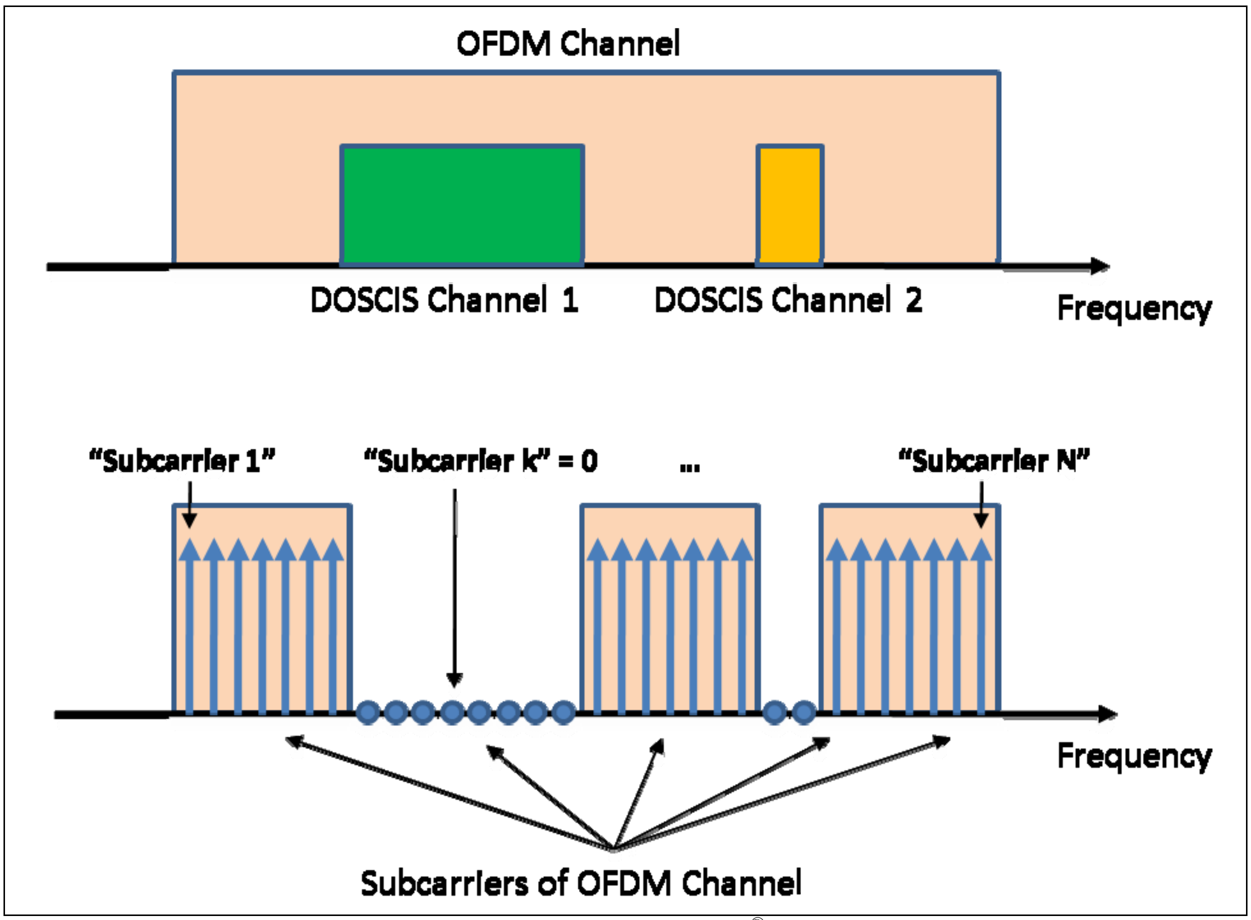

Figure 2. OFDM channels overlap with conventional DOCSIS® channels but do not interfere with them

WIMAX LINKS OVER THE AIR

The WiMAX channels form an alternative return path to the cable. They are based on the OFDM technology and present many benefits as explained in the following sections.

BENEFITS OF THE PROPOSED SOLUTION

This section demonstrates that this dual-approach proposal provides many advantages beyond the basic benefit of expanding the US bandwidth. These benefits are:

1. Backward Compatibility & Smooth Migration

An important advantage of this proposal is backward compatibility, where conventional DOCSIS® cable modems can share the cable with the new modems (Cable & Wireless) through the ability of OFDM to turn on/off subcarriers as explained earlier. The OFDM overlay approach of this solution provides smooth migration toward a new HFC network architecture. It may also provide an easy migration when midsplit bands may be introd-

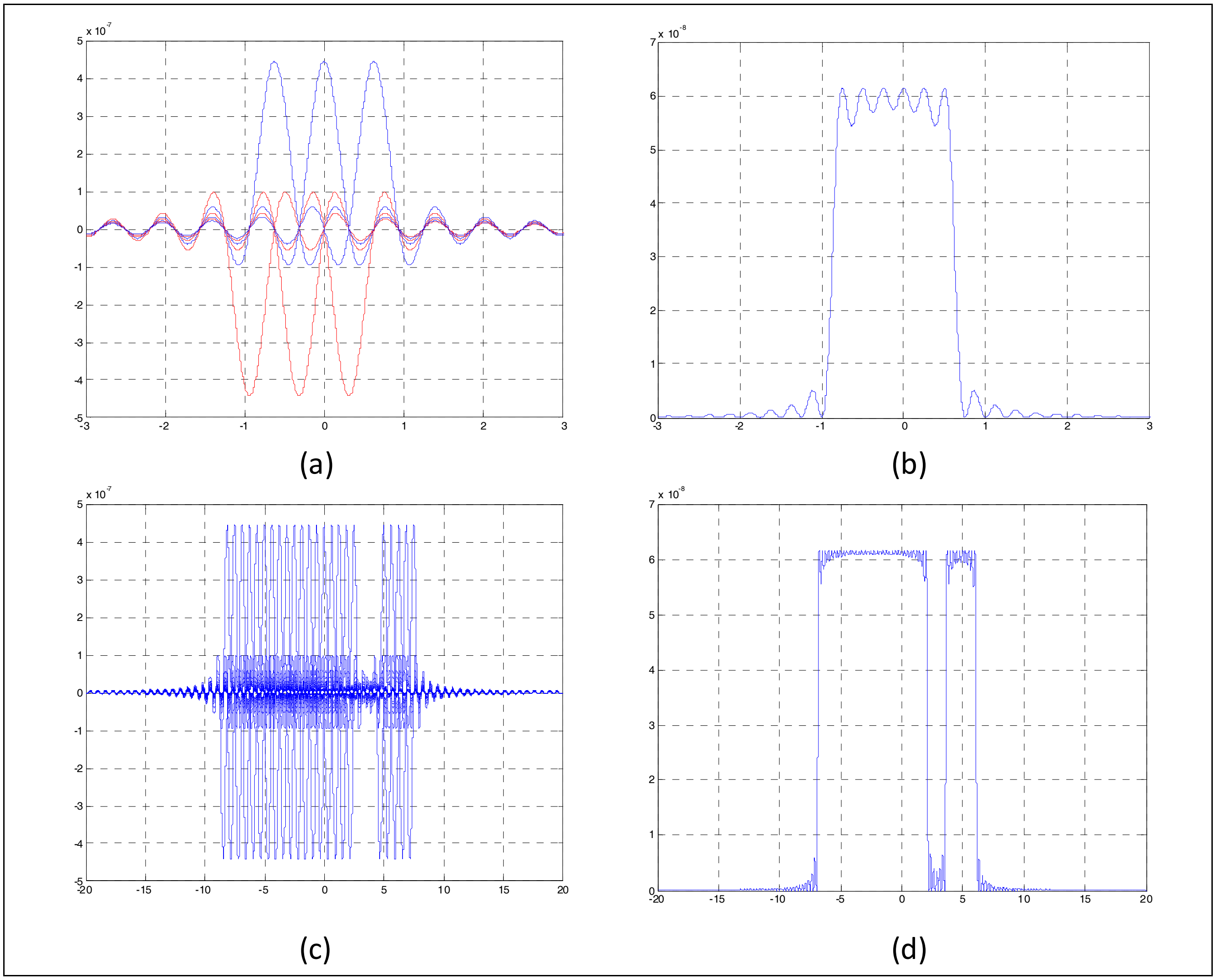

Figure 3. Architecture of OFDM signals: (a) OFDM subcarriers overlap but orthogonal. (b) PSD (w/Hz) of OFDM signal composed of the subcarriers in (a). (c) OFDM signal composed of 52 subcarriers, where 6 of them are off. (d) PSD (w/Hz) of the OFDM signal composed of subcarriers in (c) show a frequency gap within the channel. Note: all graphs are plotted versus frequency (MHz).

uced to the cable, where a single wide OFDM channel may cover two separate bands.

2. Efficient US Bandwidth Utilization

The ability of OFDM to support various channel widths and the ability of OFDM to turn individual subcarriers on and off provides better spectrum utilization by exploiting unused holes in the spectrum which may exist near the band edges or between conventional DOCSIS® channels. Moreover, the feature of dynamically allocating OFDM subcarriers to different modems provides better spectrum efficiency especially when a particular modem does not need all the subcarriers on a single channel. Efficient bandwidth utilization is also achieved using high resolution US data grants (subcarrier mini-slots) offered by the OFDM overlay technology. In particular, a subcarrier mini-slot is defined as a time-slot over a subcarrier bandwidth but not over the full channel bandwidth, as is the case in conventional DOCSIS® channels.

The inherent immunity of OFDM (and Coded OFDM) to different types of noise found in HFC plants enables the operation in challenging noise environments and provides higher goodput (useful throughput) values as little Forward Error Correction (FEC) may be needed [2].

3. DOCSIS® 3.0 US Channel Bonding

The dual-approach proposed in this article provides the flexibility to perform DOCSIS® 3.0 US channel bonding over multiple media, where service flows can be bonded over multiple channels on the cable, WiMAX link(s), or both. This, in turn, introduces evolutionary growth to the priceless US bandwidth in HFC networks.

4. Load-Balancing

Load balancing is another promising feature of this dual approach. Load balancing distributes the user bandwidth across different channels over the cable, WiMAX link(s), or both. Offering more channels through both approaches of OFDM overlay and WiMAX link provides more flexibility to the load-balancing feature, which helps in providing good Quality of Experience (QoE) service to the subscribers.

5. US Path Redundancy

One important advantage offered by this proposal is the redundancy in the return path. This feature contributes significantly in offering high-availability and better QoE services to subscribers because it eliminates or immensely reduces the service downtime, which can be very large especially in cable-related failures. One example of US cable-related failures is a noisy US band resulting from old cabling and corroded RF connections which introduce Common Path distortion (CPD) noise in addition to ingress noise and impulse noise that couple into the deteriorated cable. All these types of noise add to the common Additive White Gaussian Noise (AWGN) causing failure in communication in the US direction.

6. Wireless & Mobility

This solution adds the wireless features and mobility to HFC networks through WiMAX links over the air. Integrating this wireless technology with HFC networks enables the MSOs to utilize all the benefits offered by the WiMAX technology such as mobility, flexible channel widths and modulation profiles, dynamic resource allocation, Quality of Service (QoS), security, etc. This addition also allows the MSOs to use multi-element antennas to offer more bandwidth through spatial multiplexing and intelligent interference mitigation techniques [1]. In particular, spatial multiplexing may increase the channel capacity multiple times through utilizing various wireless paths between the transmitter and receiver using multi-element antennas. Additionally, multi-element antennas are also used with tapped delay lines to provide directional radiation patterns that increase the antennas transmit and receive gains and mitigate interference from other wireless devices [1].

7. Low Cost and Optimized Implementation

Since OFDM is the base technology for both parts of this solution (OFDM overlay and WiMAX), systems designers and RF engineers may be able to debug, design, and apply the similar solutions and optimization algorithms to both parts of the network even though they exist on different physical media. For example, the principle of allocating OFDM subcarriers dynamically based on subscribers' needs or noise pattern can be applied to both OFDM overlay channels over the cable and WiMAX links over the air.

The architecture of OFDM signals which are composed of narrow subcarriers may eliminate the need for complex pre-equalizers, which results in much simpler and cheaper PHY systems. Additionally, OFDM is based on the Inverse Fast Fourier Transform (IFFT) algorithm, which can be implemented easily and efficiently on processors and therefore produce faster and lower cost systems. Another potential benefit of using the OFDM-overlay technology is implementing a simpler US mapper (scheduler), where certain subcarriers can be assigned to different modems, services, MAC management messages, etc.

Utilizing WiMAX for the return path may provide for easier integration within the subscriber's home network, where a wireless medium is used to connect a variety of subscriber devices. In this scenario, the home network can be based on different wireless technologies such as WiMAX or Wireless Fidelity (Wi-Fi) as shown in Fig. 1. Observe that higher data rates in Wi-Fi devices use the OFDM technology which is also used in WiMAX [1]. Therefore, the wireless home network and the US return path (OFDM overlay and WiMAX) are all based on the OFDM technology, which in turn can help in the evolution of RF gateways.

Finally, employing the standards-based WiMAX technology can speed up the evolution process of HFC plants by avoiding the creation of new standards or specifications and also exploiting well-established equipment offered by different WiMAX vendors.

CONCLUSIONS

A dual-approach solution to augment the limited US bandwidth in HFC networks was proposed. The solution offered two parallel approaches: (1) OFDM overlay channels over the cable plant, and (2) WiMAX links over the air. The solution augments the current US bandwidth in HFC network through adding extra bandwidth resources (WiMAX network) and providing better bandwidth utilization (OFDM overlay). There are many advantages offered by this solution such as: backward compatibility and smooth migration, efficient US bandwidth utilization, DOCSIS® 3.0 US channel bonding, load-balancing, US path redundancy, mobility, and low cost and optimized implementation.

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Ayham Al-Banna, Ph.D.: Sr. Systems Architect at ARRIS Group, Inc., Chicago. His research interests include RF Communication, Traffic Management, QoE, and QoS. Ayham has published a book and numerous publications in the area of Wireless and Cable Communications.