Getting to 4G via Wi-Fi in the Real World

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Abstract

As the economy shrinks and the competition for profitable revenue generating subscribers increases, operators increasingly use bundled packages of services to capture and retain customers. One key tool for that is the inclusion of wireless services. This paper describes how wireless services can be effectively deployed on an MSO's existing HFC infrastructure. It describes both licensed and unlicensed technologies and how they compare. It also describes how mobility can be deployed on HFC and the difference between macrocellular and microcellular systems and their performance.

INTRODUCTION

Traditionally, cable operators have looked on wireless options associated with licensed and unlicensed spectrum as either/or propositions. But, with the emergence of fully mobile cable-optimized basestations, Wi-Fi can be used as a complement or an alternative to next-gen mobile standards that rely on licensed spectrum. Multi-radio platforms can operate in both licensed and unlicensed bands and connect directly to the HFC (Hybrid Fiber Coax) network.

One of the key business strategies for acquiring and retaining customers of the past few years has been the use of bundled service packages. In this MSOs have been uniquely positioned as the HFC offers a very cost effective platform to deliver TV, data and voice services to a customer premise. In contrast traditional Telcos has been forced to put in place extensive upgrades to their system, going to the extent of putting fiber optic connections to individual properties, in order to compete with MSOs. The next frontier in bundling is the addition of wireless services to the package.

Mobile wireless systems offer particular challenges to MSOs, notably;

- Spectrum
- Mobility

In this paper I describe the difference between macrocellular and microcellular techniques for providing wireless coverage and capacity. I also describe how the HFC can be leveraged as a mounting location for wireless basestations and some of the technologies that are required to deliver this. In conclusion I show that MSOs can deploy Wi-Fi today and achieve capacities and user experiences that are better than all of today's 3G cellular standards and the future 4G standards.

Figure 1 shows that this approach is reality today, with numerous MSO deployments of HFC based microcells in progress.

Figure 1 Wi-Fi Microcell being installed on HFC

MACROCELLS, MICROCELLS & CAPACITY

Macrocells

The traditional method of deploying wireless services used by cellular carriers has been the use of roof top macrocells. These types of cells were quite suitable for deploying services that were primarily voice orientated. A macrocell deployment has the following characteristics.

- Prone to obstructions by terrain and buildings
  - Cold spots in coverage common
  - Building shadowing causes dead zones
- Signal levels are constrained at distance by diffraction losses over buildings and into streets
  - Lower signal strengths = lower throughputs
- Frequency and spectrum re-use limits capacity at central point
  - Can't keep adding channels
- Pluses
  - Provides overlay coverage
  - Large cells mean fewer mobility events
  - Provides in-building coverage for tall buildings (3D)
- Challenges
  - Capacity and user experience

Figure 2 Macrocell approach

Microcells

The alternative approach has been to deploy microcells. These smaller cells offer the following characteristics;

- Many times the capacity of macrocells
- Go around obstructions by terrain and buildings
  - No cold/dead spots
- Signal levels are higher due to small cell sizes
  - Higher signal strengths = higher throughputs
- Frequency re-use simple
  - Reuse channels frequently
- Pluses
  - Capacity and user experience
- Challenges
  - Need more cells
  - more mobility events
  - More challenging to provide in-building coverage for tall buildings (3D)
  - Backhaul

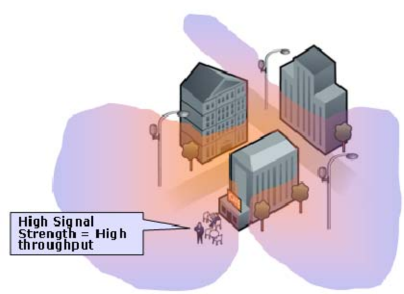


Figure 3 Microcell approach

Microcells have been used infrequently by cellular operators to date because of the challenge of getting wired backhaul to them. The high cost of deploying a fractional T1 connection into the streets has resulted in microcells being used for either cold spot (lack of coverage) of hot spot (capacity) fill-in rather than ubiquitous coverage. This has been the case for voice systems, however, as will be demonstrated, 4G systems need microcells to fulfill their capacity and throughput claims. Fortunately the MSO industry has the mounting assets required.

4G systems need microcells

One of the key differentiators of 3rd and 4th generation wireless systems as compared to the traditional cellular systems has been the use of higher order modulation schemes to deliver enhanced capacities and throughputs. MSOs are no strangers to this, with the DOCSIS® system using high order QAM to deliver bandwidth to their customers. However, the HFC is delivered to the end customer via coaxial cable, with amplifiers that keep the signal to noise high enough for all modems that are connected to the system to operate at the best modulations. A wireless system in contrast, propagates its signal over the air, and the signal that a user gets is highly dependent on their distance from the cell site. This is especially true once higher order modulations are used. This is illustrated in Figure 4.

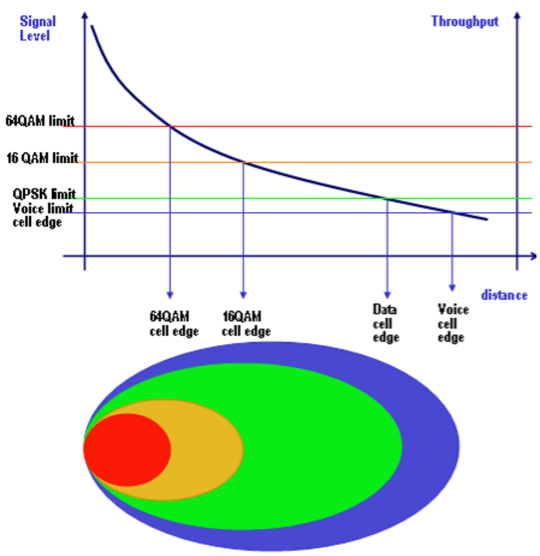


Figure 4 Modulation versus Distance

What this means to a cellular provider is that only a small percentage of the cell is covered by the highest order modulations. Given that cell site locations are driven by real estate concerns, and the customers are individuals who are mobile, it is reasonable to assume that end users are uniformly distributed throughout the cell. This means that the average throughput of a cell which also represents its capacity is degraded due to the distribution of modulation rates.

This has a profound impact on the deliverable performance from a cellular network. While most commentators describe wireless systems in terms of the peak throughput that they can deliver, or sometimes even the raw modulation rate, it is more instructive and useful to look at 2 aspects of the system in more detail.

- The peak user performance that can be expected
- The average capacity across the covered area.

To determine the average capacity of a cell we need to estimate the percentage of the cell that can operate at each modulation An example calculation is shown in Figure 5 for an LTE [1] macrocell using a 5MHz channel in a tri-sectored cell. This assumes the availability of 2 blocks of 15MHz of licensed spectrum.

Modulation	QPSK	16QAM	64QAM
Base Bits per Hz	2	4	6
Code rate	0.67	0.83	0.83
Derated bits per Hz	1.33	3.33	5
Bit Rate	6.67	16.67	25
Thoughput	5.33	13.33	20
SNR	5	15	25
Uplink Sensitivity	-97.99	-87.99	-77.99
Downlink Sensitivity	-95.99	-85.99	-75.99
BTS TX pwr	38	38	38
BTS ant gain	17	17	17
MS ant gain	-2	-2	-2
Uplink link budget			
Downlink link budget	149.0	139.0	129.0
Fade margin	9	9	9
overall DL link budget	140.0	130.0	120.0

Distance (km)		0.65	0.35	0.20
Distance (mile)		0.40	0.22	0.12
Cell Area (km^2)	1.33	1.33	0.38	0.13
Ring Area (km^2)		0.94	0.26	0.13
%		71.01%	19.53%	9.47%
Blended Data Rate (Mbps)	8.28			

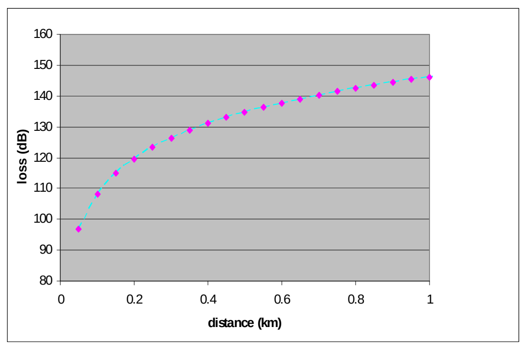
LTE Rx BW	5	MHz
subcarriers	15	kHz
subcarriers	301	
uplink resource blocks	25.083	
occupied BW	4.515	MHz
LTE BTS Noise Figure	4	dB
LTE UE Noise Figure	6	dB
LTE BTS Rx Noise Floor	-103.0	dBm
LTE MS Rx Noise Floor	-101.0	dBm

Figure 5 Example LTE link budget (macrocell)

This shows that while the 5MHz channel being used can in theory deliver a 25Mbps connection, the top modulation rate is only achieved across 9.5% of the cell. The blended capacity across the cell is 8.3Mbps. As can be seen this is far below the marketing numbers of 100Mbps download and 50Mbps upload. This capacity is shared across the entire cell/sector of the BTS. For a cell radius of 650m the circular area is 0.5 square miles. If the cell site is tri-sectored then the sector area is 0.17 square miles and the capacity per square mile is 48Mbps. This can be contrasted with the performance expected from a Wi-Fi based microcell approach where capacities of 200Mbps per square mile are deliverable today with growth to 0.5Gbps per square mile.

When similar calculations are done for today's 3G standards such as HSPA and EVDO, capacities in the order of 4Mbps per sector are achieved. Results can also be calculated for WiMAX and for use of larger amounts of spectrum. For example a blended WiMAX macrocell with 10MHz of spectrum yields 13.27 Mbps of capacity (note this is effectively less than the case shown for LTE as it is using twice as much spectrum). It should also be noted that these calculations are for the downlinks only, as that tends to drive the user experience of an end user.

The propagation model used in this case is the Empirical COST-Walfisch-Ikegami Model [2] which is representative of an "above the rooftop" macrocell type deployment. The loss versus distance and parameters used for this model is shown in Figure 6.



Frequency	f	1990 MHz
Base Station Height	h_1	27 m
Mobile station Height	h_2	1 m
Distance	d	0.7 km
Height of Building Roofs	hr	20 m
Width of Road	w	20 m
Building Separation	b	40 m
Road Orientation	p	45 degrees
City Type		0 1 = medium/suburban or 0= large metro

Figure 6 Example LTE link loss (macrocell)

MSOs have generally prided themselves on delivering the fastest user experiences, in contrast to the typical wireless system. In order to improve theses capacities, a microcellular approach is required.

Wi-Fi microcells as a complement

In the preceding sections it has been demonstrated that macrocells deliver relatively low capacities and user throughputs, but MSOs have another tool that can be used – the microcell. MSOs also have the ability to use the unlicensed frequency bands and the 802.11 Wi-Fi standard. Taking the same technical approach to a Wi-Fi based system and assessing the percentage of each cell that operates at the various modulation rates we get an average capacity of 8.3 Mbps in a 20MHz band when considering just the current 802.11b/g standards.

Modulation		cell edge	BPSK	QPSK	16QAM	64QAM
Base Bits per Hz			1	2	4	6
raw rate			6.89	13.78	27.57	41.35
Code rate			0.50	0.75	0.75	0.75
Derated bits per Hz			0.50	1.50	3.00	4.5
Bit Rate (Mbps)			3.446	10.338	20.677	31.015
Thoughput			2.76	8.27	16.54	24.81
SNR required (dB)			0	8.5	15	21
Uplink Sensitivity (dBm)			-99.97	-91.47	-84.97	-78.97
Downlink Sensitivity (dBm)			-95.97	-87.47	-80.97	-74.97
BTS TX pwr			27	27	27	27
BTS ant gain			4	4	4	4
MS ant gain			-2	-2	-2	-2
MS Tx pwr			20	20	20	20
Uplink link budget			134.0	125.5	119.0	113.0
Downlink link budget			125.0	116.5	110.0	104.0
Fade margin			9	9	6	6
overall DL link budget			116.0	107.5	104.0	98.0
Distance (km)		0.30	0.47	0.23	0.17	0.10
Distance (mile)		0.19	0.29	0.14	0.11	0.06
Cell Area (km^2)	0.28	0.28	0.69	0.17	0.09	0.03
Ring Area (km^2)		0.12	0.53	0.08	0.06	0.03
% of whole cell		40.74%	76.05%	10.86%	8.56%	4.53%
% with cell edge limit		41.22%		26.67%	21.00%	11.11%
Blended Data Rate [whole cell] (Mbps)	8.30					

Figure 7 Example Wi-Fi link budget (microcell)

This model uses a microcell power loss that was derived from empirical measurements of basestation deployed at strand height using Wi-Fi at 2.4GHz. The best fit to the data was a propagation power law of 2.8 resulting in the loss profile shown in Figure 8.

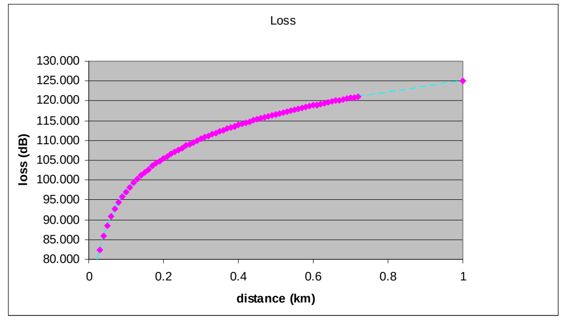


Figure 8 Example Microcell Loss

Using this number of 8.3Mbps average per Wi-Fi microcell, and using 30 microcells per square mile, we arrive at a capacity of 249Mbps per square mile, which is 5 times that capacity of the LTE macrocell. Using 802.11n, the evolution of 802.11g, capacities of in excess of 500Mbps per square mile can be achieved.

Comparison of 3G/4G/Wi-Fi systems

Figure 9 shows a comparison of the throughputs expected from various standards in the real world.

	Channel BW/Duplex	Peak user data rates (Mbps)	Typical user peak data rates (Mbps)	Wide Scale Availability (carrier)
802.11g	20MHz/TDD	22Mbps in 20MHz	4-12Mbps	Now
802.11n	20MHz/TDD	45Mbps in 20MHz 90Mbps in 20 MHz (2x2 mimo) 240Mbps indoor	10-25Mbps	2H 2009
HSDPA	5+5MHz FDD	14.4Mbps in 5MHz	1-3.6Mbps	Now
802.16e	5-10MHz TDD	27Mbps in 10MHz 12Mbps in 5MHz	expect 4-8Mbps	Early 2009
LTE	1.25MHz-20MHz	100Mbps in 20MHz DL 50Mbps in 20MHz UL	expect 6-12.5Mbps	2010+

Figure 9 Comparison of systems

A recent study by Ken Biba of Novarum [3] confirms the real world effectiveness of Wi-Fi based systems for delivering a good user experience in comparison to the 2G and 3G cellular standards that are deployed. In the study the Wi-Fi networks delivered 3 times the throughput of the WiMAX and Cellular networks with the same coverage.

A study by Nortel Networks [4] also drew similar conclusions to the above calculations. That is that the expected performance of HSPA was 3.4Mbps, LTE was 11Mbps, both on a 500m cell.

Overall this demonstrates that wireless capacities and user experiences are generally lower than that experienced by home users, but that Wi-Fi based microcells offer MSOs an important tool that can deliver superior performance.

STRAND MOUNTED WIRLESS BASE STATIONS

As mentioned earlier, MSOs have a unique asset that enables them to play a large role in the 4G wireless world. This asset, the HFC, offers the three elements necessary for deploying microcells.

- Power – Plant power, quasi square wave low voltage ac
- Backhaul – DOCSIS or fiber
- Mounting – the messenger wire

A typical strand mounted wireless BTS is shown in Figure 10.

Figure 10 Deployed Strand Mount Basestation

The basestation uses standard strand hangers for mounting and has a single connection to the HFC for both DOCSIS® and power. Various antenna options are required depending on the RF coverage that is being deployed. In order to ensure that omni directional coverage is provided, a bracket is used to offset the omni directional antennas from the basestation to avoid shadowing. Directional antennas are also possible for coverage of tall buildings or for making backhaul connections. The DOCSIS®/Power connection is made via a dc splitter and/or a power passing tap from the main coax.

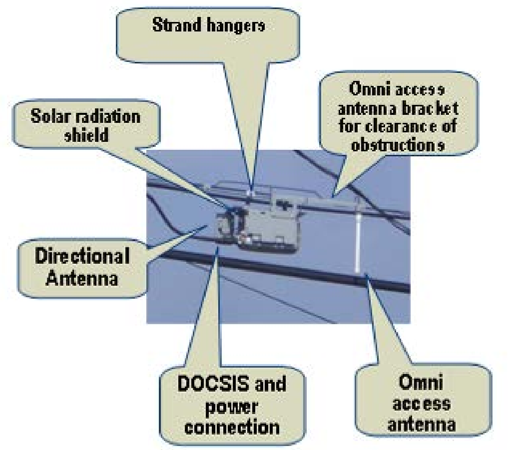


Figure 11 Strand Mount Basestation Details

The architecture of such a strand mounted basestation is shown in Figure 12. The combined DOCSIS® and power enter the unit via power protection module that splits the power and the DOCSIS® apart. This module provides filtering to prevent emissions from entering the plant and lightning and power surge protection. A power supply takes the plant power quasi square wave and converts it to usable dc voltages for the rest of the BTS.

The BTS has 2 universal radio slots, which in the example shown contain a LTE (3GPP Long Term Evolution) radio paired with an 802.11 Wi-Fi radio.

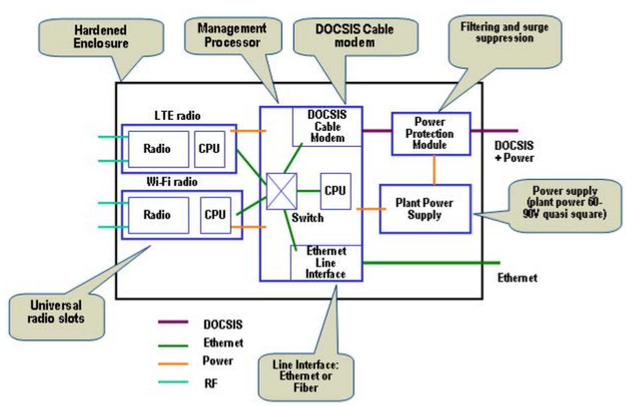


Figure 12 Inside a Strand Mount Basestation

Central to the Basestation is a control board that contains Software that enables integration into the HFC. This processor provides the packet processing to apply QoS as well as the mobility features described in the next sections.

MOBILTY IN THE HFC

One key difference between the delivery of wireless service and fixed services is the aspect of mobility. Today's HFC is designed to provide fixed subscribers with a high speed connection, and contains the assumption that the user device does not move. In most implementations there is an IP address limit per connection of 2 to 5 addresses and a MAC address limit of 8-16 devices. The network assumes that a user has a NAT (Network Address Translation) router device deployed on premise that hands out addresses to local computers. In a wireless system deployed on the HFC, the mobile devices can move between basestations at will. In fact, even a static/fixed wireless device will be mobile as variability in RF propagation and the environment means that a so called fixed device will connect to several basestations over time.

One of the main requirements is to deliver this mobility without requiring wholesale changes to the existing HFC components such as the CMTS and Fiber nodes. In order to deliver such mobility on the HFC a tunneled architecture is proposed as shown in Figure 13. The tunnels are IP constructs that can traverse a layer 2 and or layer 3 network, including a NAT device if necessary.

In order for mobility to be a seamless experience for the customer, there are some critical requirements.

- IP address of the end device shall not change.
- Customer shall not be required to login multiple times.
- Specialized Software shall not be required on the user's device.

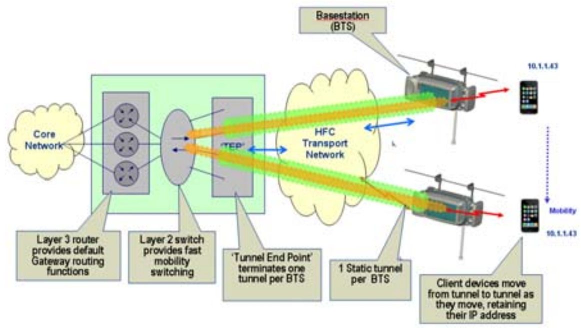


Figure 13 Tunneling approach for mobility

This level of seamless mobility can be scaled to systems in the order of 10,000 contiguous basestations. We also need to address larger scale systems and mobility between standards. To do this, a mobile IP infrastructure can be deployed as shown in Figure 14.

One might ask why not deploy a full mobile IP infrastructure to handle the mobility day one. The reason for this comes back to one of the challenges of microcells which is that there are lots of cells. This translates into a lot of mobility events in the system as the cell boundaries are frequent and users transition though cells quickly, generating a lot of mobility events. With a hybrid tunneled and mobile IP architecture, the transitions between microcells are handled at layer 2 whereas the transitions between groups of microcells and between different systems are handled at layer3.

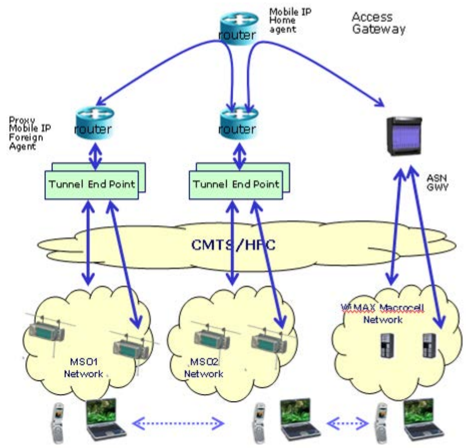


Figure 14 Mobile IP between networks

A more detailed view of the entire network can be seen in Figure 15. This shows another fundamental difference between a mobile network and a fixed network. That is the concept of centralized subscriber management.

In the classic HFC case, the modems represent the customer and the CMTS and Network can be provisioned to authorize a particular fixed device, whether that is a set top box, PVR or Cable modem. In the case of the mobile device, the device can exist anywhere on the network, and the user is attached to the device rather than a fixed location such as a home. This necessitates a centralized approach to login. This can be transparent to a user such as a SIM (Subscriber Identity Module) based authentication or MAC address based, or a web based user login.

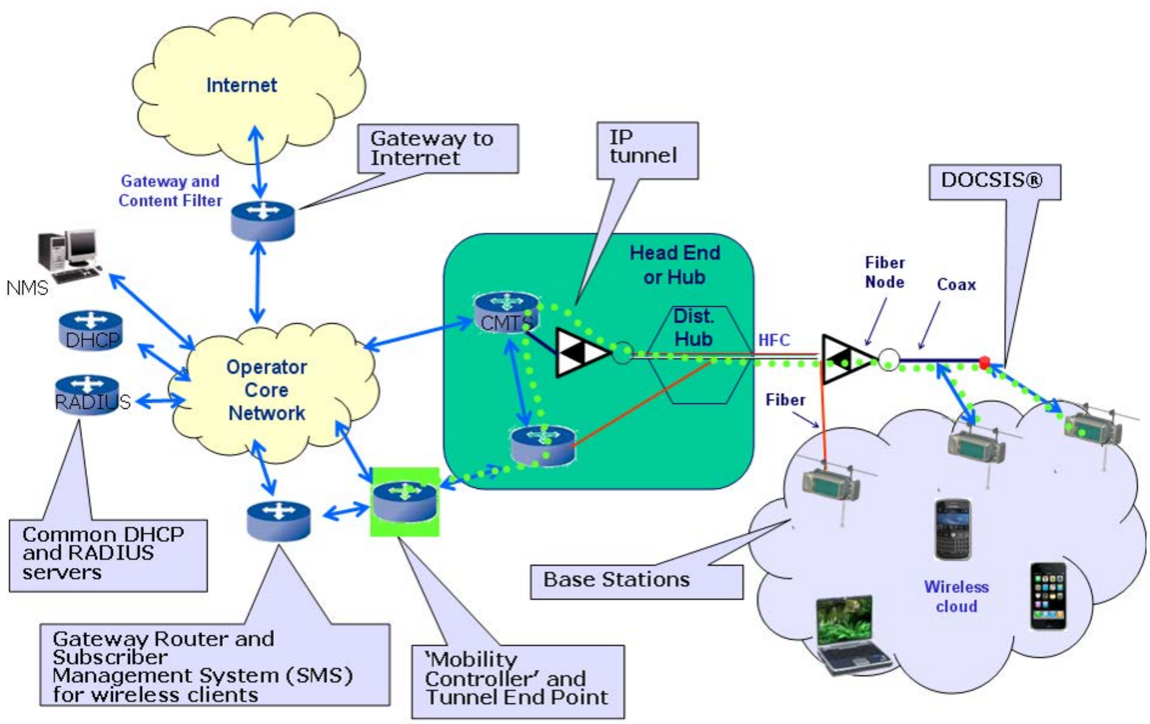


Figure 15 HFC with tunneled mobility

INDOOR WIRLESS

Indoor wireless is another part of the story that needs to be addressed. In this case, cellular technologies have struggled to deliver a consistent user experience and the experience of dropped calls within the home has been an experience that has frustrated many. In fact some cellular providers have deployed Wi-Fi already as a solution for in the home wireless using the UMA [5] technology. Others are exploring the use of Femto-cells which are miniature basestations for delivery of cellular service. This trend fully supports the argument for strand based microcells in the outdoor world, as Femtocells are becoming necessary to deliver even 3G data speeds to end users.

Fortunately the MSO/HFC friendly architectures described above can also be used to deliver wireless services into the home or small business. With the hybrid tunneled architecture seamless mobility can be provided between outdoor and indoor locations.

WHAT HAPPENS WHEN THE PLANT IS UNDERGROUND?

Of course, as ubiquitous as HFC is, not all of it is overhead strand. A reasonable percentage is underground, and is accessed from vaults and pedestals. Figure 16 shows a typical residential area pedestal with a HFC fed base station embedded.

Figure 16 Pedestal mounted BTS

SUMMARY

This paper has demonstrated that the HFC is an ideal location for hosting wireless basestations. Broadband wireless systems need microcells in order to deliver the broadband experience they promise, and microcells have traditionally been limited to locations where backhaul and power are accessible. The HFC can provide the 3 necessary ingredients (location, power and backhaul) for a microcell deployment.

Full mobility can be provided over the HFC using a tunneled architecture together with a mobile IP overlay offering a user a seamless mobile solution, while not requiring an upgrade to the HFC.

If MSOs wish to deliver the superior user experience that their customers are used to from their cable modems in the wireless world then they should consider the HFC as a key asset. Today's Wi-Fi systems offer capacities and user throughputs that are far superior to today's 3G cellular systems and to next generation 4G macrocells.

Interestingly, the 4G systems have migrated to an all IP transport system, something that Wi-Fi was designed to do from the start. This is another advantage that MSOs have, with their IP friendly networks. A Wi-Fi system deployed on the HFC can be used to deliver broadband IP wireless services to customers and as a bridge to a 4G microcellular system in an extremely cost effective manner. While not covered here, such HFC based wireless networks can also deliver a full multi-media experience, a topic for a future paper.

By using the HFC to deploy Wi-Fi today, an MSO can deploy a wireless experience that will be unmatched until 4G licensed band microcells become ubiquitous.

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