Optimizing Wireless Networking of Wi-Fi and LTE

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Abstract

The proliferation of smart devices such as iPhones, DROIDs, tablets and others has resulted in huge increases in data traffic across cellular networks. These devices support multiple wireless technologies including 3G, 4G LTE and Wi-Fi. The massive adaptation of these devices can enable Wi-Fi to play a significant role in addressing the 3G/4G mobile data networks' increasing capacity requirements. Wireline and cable operators can both provide Wi-Fi offload for wireless operators. In this paper, we show how to optimize the performance and cost of heterogeneous networks comprised of cellular and Wi-Fi technologies.

INTRODUCTION

Most smartphones, tablets and PCs in today's world support Wi-Fi technology. While historically there have been hesitations on the part of wireless operators to embrace Wi-Fi as a complimentary technology to cellular, developments over the last several years in 3GPP interoperability have been breaking down the barriers (see, for example 1, 2). It's no longer an "either/or" discussion or debate but rather a complimentary use of both cellular and Wi-Fi technologies by operators to provide their end-users with optimized access to a rich set of services. Note that some Wi-Fi network deployments may include applications that drive Wi-Fi only traffic and not cellular traffic.

In this paper, we deal with the following key questions, which have not been commonly addressed, to the best of our knowledge:

- How much traffic can potentially be offloaded to Wi-Fi networks? This helps in sizing the Wi-Fi as well as the cellular network, since the latter now needs to carry only the remaining load.
- How do we overcome the well-known problems of interoperability between Wi-Fi and cellular networks, e.g., user authentication and admission control, mobility between the two networks, interference issues, guaranteed Quality of Service (QoS), etc.
- What are the best locations to deploy Wi-Fi hotspots? Access Point footprints are quite small compared to macro cellular footprints and deploying and clustering Access Points at the right locations, especially in high-traffic areas, is critical to the service provider for getting the most out of their investment and maintaining a consistent coverage footprint for nomadic users.
- How does the economics of combining Wi-Fi and cellular networks compare with the cellular network alone? A smart combination of Wi-Fi and cellular networks can keep the costs down and yet satisfy traffic demands.

Cable operators are in an excellent position to leverage their networks not only for using Wi-Fi as an extension of fixed access broadband services, but also in partnering with wireless service providers to use Wi-Fi and offload cellular network traffic.

We present a model to assess Wi-Fi offload potential in a network, based on applications, user behavior, etc. We show techniques of creating traffic density maps and identifying high traffic areas. Finally, we present a techno-economic model to compare the network options.

CONSUMERS, DEVICES AND TRAFFIC DRIVE "INTERWORKING"

A Wireless World

Nearly every mobile device in the foreseeable future will support multiple wireless technologies including 2G and 3G[1], 4G LTE[2] and Wi-Fi[3]. Wi-Fi plays a significant role in addressing the 3G/4G mobile data networks' increasing capacity requirements. Wi-Fi, in addition to providing a wireless extension for fixed wireline broadband, has emerged as a way to gain alternative connection to the 3G/4G cellular network services while off-loading data traffic from its radio access network (RAN). The complimentary use of LTE and Wi-Fi in providing wireless services enables the network operator to balance network and transport costs, while providing the consumer with services to meet their bandwidth needs.

Forces Driving Traffic Explosion

While early days of mobile data traffic primarily consisted of applications such as occasional web browsing, running search engines or instant messaging, today's mobile data traffic is dominated by richer applications such as video streaming, social networking and large file transfers. In many markets, voice and SMS traffic is being replaced by various web-based applications. Looking into the future, the five main applications for mobile data are considered to be cloud computing, different types of streaming, back-up and storage, full motion gaming and video communications.

There are several factors that are combining to trigger the mobile data explosion. On one end of the spectrum are technology factors like advancements in wireless technologies as well as end user devices. At the other end, cloud-based applications are encouraging social networking behaviors that were unthinkable of only a couple of years ago.

While early cell phone devices were not ideally suited for data communications, the introduction of QWERTY keyboards was the first game changer. Touch-screen phones brought on another round of evolution along with dramatic improvements in human-machine interfaces and software applications, all triggered by advancements in computing power and storage that can be packed in a small form factor. While PC data consumption on mobile networks remains high, the data usage by hand-held devices/tablets has been increasing sharply.

`Figure1` below provides Bell Labs' projection of data traffic over the next several years.

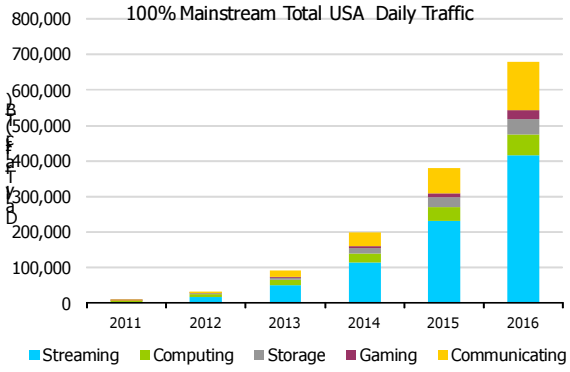

Figure1: Mobile Data Projections

Wi-Fi and LTE Applications

At the highest level, cellular networks can be used both as a mobile broadband solution, such as making a video call riding a train or bus, and as a non-mobile broadband solution, such as sitting in the backyard watching a video clip. Wi-Fi, on the other hand, is primarily used today as an extension to fixed broadband solutions. `Table 1` below

[1] 2nd and 3rd Generation wireless standards that use licensed spectrum for Wide Area Networks.

[2] Long Term Evolution, a 4th Generation (4G) wireless standard that uses licensed spectrum for Wide Area Networks.

[3] A wireless technology that uses unlicensed spectrum for Local Area Networks.

illustrates the common types of applications vis-a-vis technologies.

Applications	Cellular	Wi-Fi
Fixed	Yes	Yes
Nomadic	Yes	Yes
Mobility	Yes	Very limited

Table 1: Applications & Technologies

Additional discussions describing key characteristics of cellular and Wi-Fi technologies are provided below.

Cellular

- 3G/LTE enables a high speed data connection to services when a user is mobile, in a fixed location, or when Wi-Fi is not available in a wireline broadband extension (fixed location) scenario.
- Cell site serving areas of several Km, depending on antenna height, location and geography; coupled with complex robust mobility algorithms; these help facilitate effective mobility hand-offs at vehicular speeds.
- A comprehensive security framework maintains secure connections and enables fast handoffs.

Wi-Fi

- An extension of wireline broadband via radio for "the last 100m". This includes the use of Wi-Fi hotspots in public locations, homes and enterprises.
- Data offload of licensed spectrum RAN networks using radio for "the last 100m" and offloading to broadband wireline connections.
- Nearly every mobile device and broadband modem today has built-in Wi-Fi capabilities. Many devices today can automatically search for available hotspots or can even themselves serve as Wi-Fi hotspots for other Wi-Fi devices.

Using Wi-Fi in Real-Time Mobile Applications

There are major challenges of using Wi-Fi in a real-time mobile solution in an uncontrolled public environment. These are:

- Interference – Wi-Fi uses unlicensed spectrum; a limited number of overlapping channels and uncoordinated neighboring Access Point deployments and spectrum used by competitive providers or even residential or enterprise users. This can result in interference, which in turn can limit capacity, mobility and service continuity.
- Mobility – Wi-Fi is intended as a short range wireless solution. Mobility is limited to slow pedestrian speeds. Wi-Fi mobility is defined in IEEE standards 802.11r and is generally supported within major vendor products. Not all vendors have implemented 802.11r and it is not clear whether 802.11r will be required for Wi-Fi Alliance certification. IETF is also involved in defining Wi-Fi mobility with RFC3990. Mobility at vehicular speeds is impractical due to small wireless coverage areas of Access Points, the challenges associated with hand-offs and admission control, and a lack of algorithms needed for service continuity. There is also CAPWAP, which is an IETF standard defined in RFC3990, which addresses mobility.
- Admission control (in the form of resource management) – at the time of a session handover from one Access Point to another Access Point. In the worst case, it would be similar to starting a new session for best effort traffic, though there is separate signaling that is used in 802.11 for resource reservation. Major vendors are addressing this and some may be providing seamless handoffs.
- Re-association with the target Access Point – requiring a large number of roundtrips for authentication. Security throughout mobility events, like handoffs, is not maintained, and has to be fully re-

established. 802.11r may help in reducing the number of roundtrips for the delay.

- Radio resource management granularity limits the ability to share channels between many users. This limitation is generally not noticeable in fixed and nomadic applications; it is an impediment for dense use mobile applications.
- Propagation characteristics at 2.4GHz ISM band are subject to significant interference; at 5.1GHz, signal strength fades away rather quickly resulting in smaller cell ranges and the device eco-system is still developing.

Addressing Key Wi-Fi Challenges

3GPP, working with other industry bodies, has developed two fundamental approaches for integrating Wi-Fi with cellular technologies. Figure 2 shows the architecture where the cellular operator has no control over the Wi-Fi Access Point, and Figure 3 shows the architecture when the operator has full control over the Access Point.

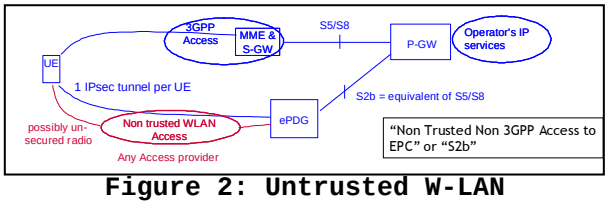

Figure 2: Untrusted W-LAN

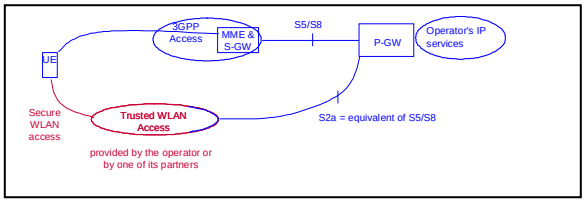

Figure 3: Trusted W-LAN

Additional developments in 3GPP continue in the form of initiatives like Access Network Delivery Selection Function (ANDSF) where the cellular network assesses the quality of experience in the Wi-Fi and Cellular networks for given applications and based on policies, may switch the user from one technology to the other. 802.11u also defines another way to achieve this. HotSpot 2.0 and Wi-Fi Alliance activities not only enable Wi-Fi roaming among operators but also open the doors for further integration between Wi-Fi and cellular networks.

OPTIMIZING WI-FI AND LTE NETWORKS

Traffic Offload to Wi-Fi

A significant part of mobile data traffic is considered nomadic and not necessarily mobile, thus making many cellular users amenable to Wi-Fi offload. It is likely that Wi-Fi offload may grow today from roughly 22% of traffic in North America to over 30% within the next four years. The amount of offload will depend upon various factors like residential broadband penetration; ubiquity of public Wi-Fi hotspots, mobile data tariffs, and technology evolution for seamless Wi-Fi-cellular integration etc., the potential for offload could be greater than 70% as seen from various studies in certain international markets.

Optimizing Wi-Fi Hot Spot Locations

Wi-Fi offers good user throughput in an interference-free environment. Figure 4 provides a comparison between different technologies, based on 3GPP simulations. The Wi-Fi value is based on typical environment for today's 802.11b/g deployment with 20 MHz channels. Pure 802.11n environment is expected to achieve 50 Mbps+ average user throughput with a 40 MHz channel.

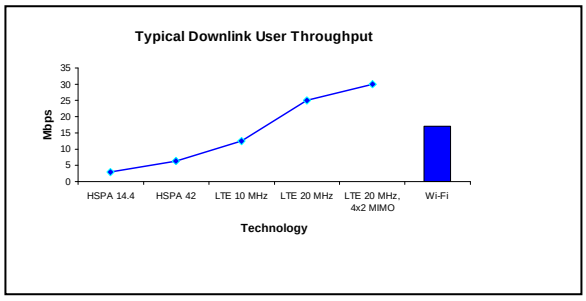

Figure 4: Throughput Comparison

However, Wi-Fi Access Points have small coverage areas, compared to macro cells. A comparison between technologies of capacity per unit area of coverage for typical dense urban environment is shown in Figure 5 below. While the cell range for a typical macro cell is 1.2 – 1.5 km in an urban environment, typical Wi-Fi Access Point range is around 30m and generally not too much more than 100m. Typical downlink sector throughput for 3G HSPA is around 6.7 Mbps whereas for 20 MHz LTE, it can be around 30 Mbps. For 802.11g, typical downlink user throughput is around 17 Mbps.

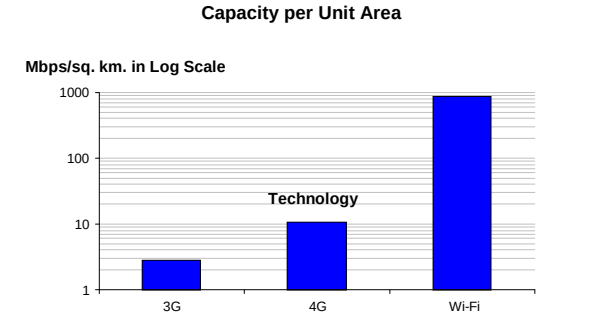

Figure 5: Unit Area Capacity

The challenge, thus, becomes how to enable maximum traffic offload Wi-Fi hotspots. Bell Labs analysis from various real networks has shown that a relatively large volume of mobile data traffic (50% - 60% or more) is often contained in a relatively small geographical area (10% - 15%) under a macro cell coverage area. Figure 6 shows the relationship between geographical area and amount of traffic during busy hour in a macro cell in a large North American city – in this particular example, only about 8% of the geographical area contains 60% of mobile data traffic.

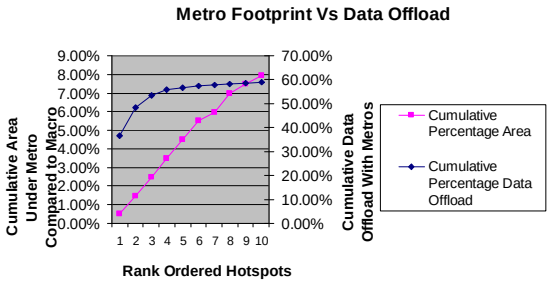

Figure 6: Traffic Density

To help address this challenge, industry techniques have been developed to create traffic density maps. This helps make a well-informed decision on placement of the Wi-Fi Access Points.

Techno-Economic Analysis

While the cost of a consumer Wi-Fi Access Point is almost negligible compared to the cost of cell site equipment, the cost of carrier grade Access Points is significantly higher than the cost of consumer Access Points. First, environmental hardening and security costs add significantly to capital expenses. Additionally, ongoing costs of backhaul and site rental significantly impact the Total Cost of Ownership (TCO). But overall, carrier grade Access Point costs are lower than macro cell site equipment.

Whether Wi-Fi deployment is economical or not depends upon a wide range of factors, including technical as well as commercial factors. In Figure 7 below, we provide a simple normalized cost comparison, using a subscriber's monthly usage as a reference.

The cost points are used from a typical large wireless operator in Europe. The reference coverage area is the footprint of a macrocell in a large European city. It may be noted that the cost points for the Wi-Fi Access Points are for environmentally hardened network elements as required for outdoor deployment, which are significantly higher than indoor Access Points.

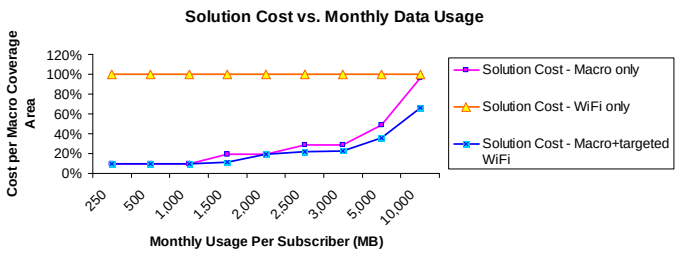

Figure 7: Technology Cost Comparison

The figure clearly shows that covering the entire macro footprint with Wi-Fi Access Points is an impractical solution. A macro-only solution is suitable for low data usage per subscriber but as the traffic per subscriber increases, macro complemented with targeted Wi-Fi deployment becomes the cost-optimal solution.

SUMMARY

Wi-Fi and LTE each have their own set of applications, but are most importantly complimentary:

- Wide area coverage with full mobility using licensed spectrum base stations with higher power and operating via higher towers (e.g., LTE) as a compliment to lower power unlicensed spectrum street level or campus environment deployments (Wi-Fi).
- Coverage and capacity limited network design that is independent of local deployments of other WLANs where the design can be impacted negatively if another WLAN is deployed nearby.
- Effective offloading of data traffic from congested cellular networks can be achieved by transporting this traffic over wireline and Wi-Fi facilities while enabling the user to enjoy the rich applications provided by these networks.
- Roaming capabilities and common authentication methods using the Wi-Fi network are adopted and certified by the Wi-Fi Alliance4.
- Careful identification of dense traffic areas and locating Wi-Fi Access Points at those locations is a key to efficient cellular-Wi-Fi integration.

Cable operators can leverage their networks not only for using Wi-Fi as an extension of fixed access broadband services, but also in partnering with wireless service providers to use Wi-Fi for offloading cellular network traffic. Optimizing the performance and cost of heterogeneous networks comprised of cellular and Wi-Fi technologies is critical for performance, customer satisfaction and cost management.

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[4] HotSpot 2.0 standardization effort and certification is expected in mid 2012.