# *Musings on Wi-Fi, Femtocells, and the mobile Internet*

*Steve Hratko*
*July 4, 2009*

The primary method for accessing the Internet in the next decade will be via a mobile device of some sort. Options include laptops, netbooks, smartbooks, mobile computers, feature phones, etc. There have been many attempts made at forecasting the growth in mobile Internet traffic. Cisco's own VNI forecast points to a 66 fold growth in mobile traffic over the next five years. Other forecasts point to even higher growth rates. This all sounds very exciting unless of course it is your job to cost effectively add enough capacity to the network to meet this demand. The two primary areas that need to be considered are the Radio Access Network (RAN) and the mobile core. Of the two, the RAN is by far the most difficult to scale. There are three primary methods for scaling RF capacity and they are to add more spectrum, increase spectral efficiency (bits/sec/Hz), and get much higher spectral reuse. The latter is usually accomplished with much larger numbers of much smaller cells.


**Figure 1: Cisco's VNI Study**

Depending on the geography, it might be possible to double the available licensed spectrum by the middle of the next decade. This is not without challenges as most spectrum under 3 GHz is already claimed for some purpose or other, and much of that by broadcasters, governments and the military. Moving organizations off of this spectrum is time consuming and can be politically difficult.

Spectral efficiency is getting harder and harder to improve upon. Best estimates are that it might be possible to triple average spectral efficiency over the next 5 years. Figure 2 is courtesy of Moray Rumney of Agilent Technologies. Today's HSPA networks (3GPP Rel 6) can deliver approximately 1/2 a bit/sec/Hz on average. Improving on this number will require advanced antenna technologies like MIMO, new modulation technologies like OFDMA and more advanced coding schemes.

If we multiply these first two numbers together we get six, but that is a long way from 66. Clearly the rest will have to come from much higher spectral reuse, which means much smaller cells. The options here are Wi-Fi, microcells, picocells, and femtocells. All will have a role to play in the build-out of the mobile Internet. Femtocells and Wi-Fi are very strong indoor local area radio technologies and the good news is that most mobile data traffic originates from indoors (typically > 80%).

**Table 1. LTE, LTE-Advanced and IMT-Advanced performance requirements**

| Item | Sub-category | LTE (3.9G) target[4] | LTE-Advanced (4G) target[2] | IMT-Advanced (4G) requirement[5] |
|---|---|---|---|---|
| Peak spectral efficiency (b/s/Hz) | Downlink | 16.3 (4x4 MIMO) | 30 (up to 8x8 MIMO) | 15 (4x4 MIMO) |
| | Uplink | 4.32 (64QAM SISO) | 15 (up to 4x4 MIMO) | 6.75 (2x4 MIMO) |
| Downlink cell spectral efficiency (b/s/Hz/cell) Microcellular 3 km/h | (2x2 MIMO) | 1.69 | 2.4 | |
| | (4x2 MIMO) | 1.87 | 2.6 | 2.6 |
| | (4x4 MIMO) | 2.67 | 3.7 | |
| Downlink cell-edge spectral efficiency (b/s/Hz/user)* | (2x2 MIMO) | 0.05 | 0.07 | |
| | (4x2 MIMO) | 0.06 | 0.09 | 0.075 |
| | (4x4 MIMO) | 0.08 | 0.12 | |

**Figure 2: The truth about spectral efficiency**

Data by its very nature can be very difficult to use when you are outdoors and on the move. Unlike a voice call which only requires listening and talking, data usually requires that you look at a screen and the requirement to actually "look" severely limits what else can be done at the same time…. or at least what else can be done safely!

So how can femtocells and Wi-Fi access points be used to solve our mobile Internet scaling problem?

Wi-Fi has the advantage of already being widely installed in homes, businesses, and places where people congregate. It is very inexpensive and available on just about every laptop that ships these days. It is also finding its way onto most high-end data-centric mobile devices. Other advantages include 80 MHz of spectrum in the 2.4 GHz band and even more up in the 5 GHz band (See figure 3), a huge ecosystem, and faster versions based on 802.11n are on the way.

It is also a very simple technology that is well suited to a local area environment and it tolerates interference reasonably well. It is ideal for the handling of what can best be called low-value, high-volume traffic like file sharing applications, web browsing, streaming of video (YouTube for instance), and anything else that works well in a "best effort" environment and needs lots of bandwidth. It also offers a speed and latency advantage over macro cellular network, but it remains to be seen if this advantage holds up against femtocells. As a general rule 802.11b is good for about 5 Mbps, 802.11b/g are good for about 25 Mbps, and 802.11n is good for about 100 Mbps in actual throughput.

Femtocells were originally envisioned as a way to solve the in-home coverage problem for mobile voice calls. It was basically thought of as a voice solution since Wi-Fi was already broadly deployed for data. Femtocells require broadband backhaul and the thinking was that femtocells could piggyback on the broadband link put in to support Wi-Fi (in most cases). Without Wi-Fi in the home, the femtocell would have to absorb the full cost of the broadband backhaul which would break the business model. This is an important point. These two technologies complement each other and allow the user to extract maximum value from the broadband service that they pay for on a monthly basis. That doesn't stop femtocells from also picking up data traffic from mobile devices, especially if that traffic is headed for the mobile operator's data center. Data traffic represents the lion's share of the 66 fold increase in mobile Internet traffic that we can expect to see over the next 5 years. Now how might femtocells and Wi-Fi work together to address the data challenge?

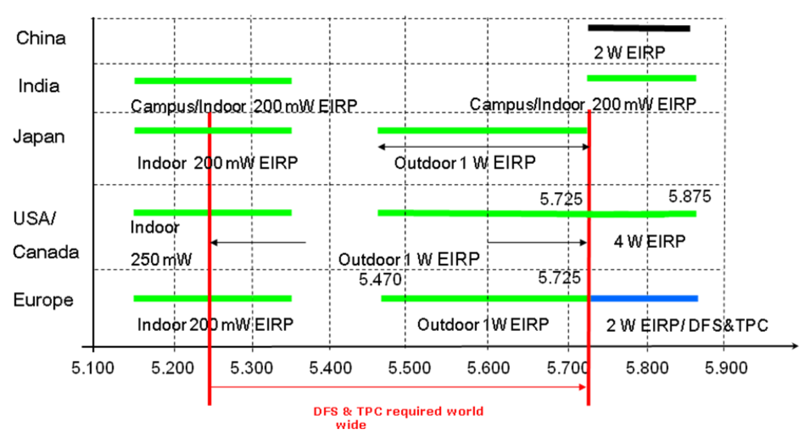


**Figure 3: Unlicensed spectrum in the 5 GHz band**

Most mobile data is headed for the Internet and would best be served by Wi-Fi, especially if it is high-volume and relatively low-value traffic.  Passing this traffic through the mobile operator's data center will add cost and latency without improving the user experience.  The cost comes from all the equipment that the traffic must transit as it hairpins through the mobile operator's data center and back out onto the Internet.  This equipment includes devices like firewalls, IPSec concentrators, femtocell gateways, SGSNs, GGSNs, load balancers, catalyst switches, etc.  This can be mitigated to a large extent by allowing local break-out at the femtocell.  In this scenario traffic that is bound for the mobile operator is sent over an encrypted tunnel to their data center and traffic bound for the Internet is sent directly to the Internet via the customer's broadband service in exactly the same way that Wi-Fi traffic is handled.  Extending femtocell technology to allow local breakout is now a project within 3GPP (The 3rd Generation Partnership Project) called LIPA (Local IP Access).

| | 3G | EDGE | Free Wi-Fi | Private Wi-Fi |
|---|---|---|---|---|
| Average Download Speed | 955.6 Kbits/s | 218.4 Kbits/s | 2,502.0 Kbits/s | 2,905.3 Kbits/s |
| Average Upload Speed | 152.6 Kbits/s | 37.3 Kbits/s | 773.9 Kbits/s | 738.8 Kbits/s |
| Average Latency | 484.2 ms | 907.3 ms | 205.0 ms | 184.4 ms |

Speedtest application running on the iPhone
500,000 downloads & uploads tested worldwide
*http://www.xtremelabs.com/2008/12/4/what-is-the-real-speed-of-your-3g-connection*

**Figure 4: Comparing Wi-Fi and 3G average throughput**

Femtocells will find their sweet spot with traffic that is more high-value and low-volume like voice, push-to-talk, and other isochronous applications that will emerge.  It can also be a nice data solution in homes where the available unlicensed spectrum is cluttered with other things (wireless speakers, microwave ovens, laptops, cordless phones, etc.).  With the data traffic increasing at better than 100% year-over-year and voice traffic increasing at a much lower rate (both depend on geography) there will be a decided shift to data traffic in terms of volume.

A good estimate is that in the next few years we could expect Wi-Fi and femtocells to be carrying >90% of mobile Internet traffic with macro cellular approaches carrying <10%.  This seems reasonable given that most mobile data is consumed when the user is indoors and most certainly not moving.  Now let's look a bit deeper at the advantages and disadvantages of the various in-home solutions.

While almost all data-centric devices are Wi-Fi enabled, it isn't always easy to use and it does represent an additional drain on the battery.  This probably isn't a big issue when you are at home as AC power outlets are readily available, but may be an issue at other indoor locations.  Clearly the IEEE will continue to work on power control, but the more radios that are turned on the greater the power drain.

Ease of use is also an issue with Wi-Fi as the user must get involved in selecting from the available networks (SSIDs).  This selection is made more difficult because the SSID gives no indication of what services are available, whether or not that user can access those services, and any roaming arrangements.  Fortunately none of these issues are a factor in-home use and the work of the IEEE 802.11u committee should go a long way toward improving the Wi-Fi connection management experience when out and about.  802.11u will allow the Wi-Fi network to advertise additional capabilities pre-association.  High-end mobile devices can then use this information to make informed decisions about the usability of the Wi-Fi network.

Wi-Fi also has the wonderful capability of allowing mobile operators to offload the low-value, high-volume traffic onto someone else's network. This is especially compelling when most data-centric devices are on flat-rate all-you-can-eat billing plans. If there is no incremental revenue associated with carrying this traffic, then it is best to hand it off to another operator.

Femtocells have some very compelling features like being able to seamlessly handoff connections to the macro cellular network. Depending on the application this could be a very nice feature. Voice and video streaming are two applications that do not respond well to a change in their IP point-of-attachment. Other applications like email, IM, web browsing, and even a well designed VPN will not have a problem when the IP point-of-attachment changes. A dual-mode connection manager (one that handles both Wi-Fi and cellular radios) would be a very nice feature on a high-end mobile device. It would select the appropriate radio based on where the user is, what they are trying to do, and the capabilities of the available radios (see the 802.11u discussion).

The future clearly looks bright for a very tight marriage between licensed RF technologies and Wi-Fi. We can expect to see Wi-Fi on most high-end data-centric mobile devices. It isn't clear that mobile operators need to own Wi-Fi assets, but there is great value in making sure that all data-centric devices that they sell are Wi-Fi enabled.

Mobile operators are learning to love Wi-Fi (and Femtocells) and they will both play a CRITICAL role in the cost effective build-out of the mobile Internet.