IEEE ComSoc Feb 21, 2007 meeting + follow-up on Metro-Scale Mesh Networks

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Introduction

At the IEEE ComSoc-SCV chapter's February 21st, 2007 meeting, Narasimha Chari, Tropos Networks' Chief Architect and Co-Founder, provided some very keen insights into the current architecture of broadband wireless mesh networks for the metropolitan area. Over the last two or three years, metro mesh networks have been deployed by Wireless Internet Service Providers (WISPs), municipalities, and government agencies. Mr. Chari also gave the audience a glimpse of what the future might hold for metro wireless networks, including the role that WiMAX might play– both for backhaul and also for a pico-cell coverage scenario that might replace the WiFi mesh router sub-network.

Metro-scale Wi-Fi mesh networks have been gaining in popularity as a vehicle for delivering high-speed mobile broadband services. The majority of users are "nomadic," in that they move from one location to another within the metro when they access the Internet. However, there are several installations where vehicular mobility is provided, e.g. within a car, bus, or train. Mobile WiMAX – being increasingly promoted for "personal broadband services" – may play a role in the future mobile Internet, but with smaller cell sizes than now envisioned.

Mr. Chari discussed the rich set of applications and devices that comprise the Metro Mesh Wireless Network, its drivers and requirements, and broad industry trends. The size and density of these mesh architectures was described along with some of the key challenges, e.g. providing consistent user experience (same bandwidth, no dropped sessions, etc) across the metro mesh.

Metro Mesh Deployments and Architecture

While WiFi was developed as a local area wireless network for indoor use, the metro mesh takes WiFi networks to metro scale outdoor networks. In less than 30 months, over 500 cities and 29 countries have deployed Metro Mesh WiFi networks- including Wireless ISPs (WISPs), as well as municipalities/ public service / government agencies. The cities of Mt. View(CA), Anaheim (CA), St Cloud (FL) were cited as examples. In St. Cloud, it was said that 79% of residents had logged in to use the wireless network.

One of the reasons for the popularity and growth of these metro mesh wireless networks is the declining costs of WiFi hardware. Because of its ubiquity due to wide usage in home networks, WiFi components have been on a sharp downward cost curve, which has made outdoor deployment in the metro area commercially attractive. Please see the illustrations of WiFi popularity and cost advantages in Figure 1 and 2., respectively.

These metro mesh networks are comprised of three sub-networks:

1. **Access layer**: primarily 2.4 GHz unlicensed operation between WiFi client devices (notebook PCs, PDAs, etc) and the Access Point/ WiFi Radio (typically mounted on a light pole or rooftop). There are different types of clients accessing these networks. While most municipal WiFi users are outdoors, WISPs and other telcos provide "wireless DSL" service to indoor users. In several cases, vehicular mobility has been deployed (which is beyond the scope of the IEEE 802.11 WiFi standard). Oklahoma City, OK was cited as an example of a mobile mesh network where 850 police cars have antennas mounted on the trunk of their vehicles. Of course, this requires an even more sophisticated routing algorithm as a fairly steady Signal to Noise ratio must be maintained as the client moves across the mesh network in a vehicle.

2. **Mesh Routing layer**: consisting of mesh- interconnected routers with WiFi operating at either 2.4 GHz or 5.8 GHz. A key attribute of these mesh routers is their proprietary **routing algorithm**, which has to be very adaptive to the RF environment, weather, tree leaves and other potential signal blocking objects, cognizant of power levels, and be aware of changing (vs fixed) location of clients. The bandwidth provided per session should be maintained, independent of the user's location and sessions should not be dropped due to changing RF or other interference (which is typical when using licensed spectrum, particularly in the 2.4 GHz band.

Some of the mesh routing sub-network functions are: route selection, determining the best channel to operate on, transmit power level and data rate selection based on the RF environment, session persistence, seamless mobility, monitoring for interference, tracking aggregate bandwidth, S/N ratio and other parameters.

There are typically 20 –30 users per Router. The router placement or density within a metro area varies, but it is typically 30 – 40 Routers per square mile.

3. **Backhaul**: a mix of point to multi-point proprietary broadband wireless technologies in the 5 GHz band (mostly from Motorola) and pre-WiMAX/ Fixed WiMAX products (e.g. from Alvarion and Aperto Networks) are used from the wireless Router Mesh sub-network to a telco central office (or point of presence). In addition to wireless backhaul, fiber optic backhauls- either point to point or in a ring configuration- have been deployed. Typical backhaul link speeds are in the order of 10 –20 M b/sec.

What Does the Future Hold for Wireless Metro Networks?

Location based services is one of the near term technologies being developed. The concept is to identify the client's location/ tele-presence and provide local advertising and requested merchant information that are within a few blocks away. Note that GPS systems in cars (like mine) have a limited capability to do this now. Such "location based" services could generate additional revenue for WISPs or municipalities that have deployed wireless broadband networks.

IEEE 802.11n, with its higher PHY data rate and improved MAC, is intended for indoor use, but could find its way into the mesh WiFi network. It would allow mesh links to operate at higher data rates. Maximum Ratio Combining (MRC) is a technology to be used on 802.11n uplinks. It was cited as an enabler to improve coverage for multiple clients

WiMAX: It's quite likely that Fixed **WiMAX** (IEEE 802.16- 2004) will be used for wireless backhaul, provided the network provider obtains licensed frequencies. Mr. Chari opined that it would take several years for **Mobile WiMAX** (IEEE 802.16e or 802.16–2005) clients to be ubiquitous and embedded in notebook PCs, tablets, and hand held devices/PDAs. Hence, he sees the Wireless Access sub-network continuing to be dominated by WiFi, as that is what will be embedded in client devices. While many pundits believe that Mobile WiMAX (IEEE 802.16e) will be the technology of choice to replace the Mesh Router sub-network with WiMAX Base Stations, Mr. Chari did not comment on that possibility. A key attribute of Mobile WiMAX is that it was designed with the mobile user in mind, while WiFi was not.

Mr. Chari did make a very interesting observation regarding the **WiMAX macro cell+ topology** that is currently being promoted: The macro cell coverage would be replaced by a **Pico Cell topology** within the metro area. He contended that smaller cell sizes were mandatory if the network operator wanted to guarantee symmetrical bandwidth within a cell, provide indoor (as well as outdoor) coverage, and avoid dropped sessions for mobile clients. Maintaining a steady uplink speed was cited as a critical factor for a smaller cell size. Further, Chari stated that the Pico Cell mesh network would support all broadband wireless technologies (proprietary, WiFi, WiMAX, and possibly 3G/4G).

+ The WiMAX cell size is the geographical area and maximum number of clients served by a given WiMAX Base Station. Cell sizes are typically squiggles rather than circles, with varying size depending on line of sight vs. non- line of sight obstacles in a given geographical area.

This author believes that the Macro Cell vs Pico Cell size for mobile WiMAX is a tradeoff between uniform performance (consistent symmetric bandwidth, coverage for mobile/ nomadic clients, no dropped sessions) vs. the higher cost of having more cells (and Base Stations) to cover a given size metro area.

<u>Speaker's follow up comments on WiMAX pico-cells:</u>

Mr. Chari had several post meeting comments on this topic, noted below with the author's copy editing superimposed:

"The drivers for WiMAX pico-cells are likely to be indoor coverage, reliable connectivity, high throughput (downlink, but more importantly the uplink) near the cell-edge and more uniformly spread out capacity. The macro-cell approach is a holdover from the cellular architecture (EV-DO/CDMA, etc) that WiMAX is trying to take on.

On the other hand, Wi-Fi networks today offer bi-directional megabits-per-second throughput through 90+% of the coverage area and users are accustomed to reliably getting those speeds from hotspots and on WiFi metro networks.

If WiMAX is to take over the mantle from metro Wi-Fi, it is going to have to offer better performance than metro Wi-Fi (not just better performance than EV-DO or other 3G data technologies like HSPDA). In order to do that, it will need pico-cells. And, of course, WiMAX has a lot of catching up to do (with respect to WiFi) in penetration into consumer devices.

While pico-cell architectures need more cells to cover a given area, the cells can operate at lower power, need to support a smaller number of users per cell, so they can be much cheaper than the typical macro-cell Base Station. So these two tendencies might balance out. With Wi-Fi, we're seeing CAPEX of ~$100K per square mile and I would venture to guess CAPEX of that order of magnitude for pico-cell WiMAX."

Epilogue: Intrigued by the WiMAX pico-cell scenario, we did some checking and discovered a small company –PicoChip- that is developing silicon for WiMAX pico-cell architectures. Please refer to the following presentation: http://www.picochip.com/downloads/WiMAX_HSDPA_and_Beyond_The_Changing_World_of_Wireless_Rupert_Baines.pdf

(There may be other presentations on their site that might also be of interest).

Coopers law is cited on slide 31 as being principally responsible for the dramatic increase in wireless capacity- the **reuse of frequencies in smaller and smaller cells**. Slides 32 and 33 illustrate the better coverage and cost savings of Pico-cells. Slide 32 looks at in-building coverage, which is cited as critical for wireless broadband access. Building loss (especially with metal windows) is a key obstacle limiting indoor coverage (and user density). Slide 33 focuses on cost issues. The conclusion is that **Pico- cells significantly improve both CAPEX and OPEX.** Comparing these costs ($/cell) against K b/sec/cell.

Picochip concludes:

1. For CAPEX: Macro-cells are good for low user density; micro- cells are best in the middle; while Pico-cells are best for high density areas. Pico-cells exhibit a constant cost of $4K/cell up to 3.5M b/sec/cell. Then the cost rises steeply to $8K/cell up till 4M b/sec/cell. From that aggregate speed/cell CAPEX remains constant at $8K/cell till the capacity max's out at 5M b/sec/cell. This contrasts to

a linearly rising CAPEX for the macro cell, which tops out at $16K/cell at 5M b/sec/cell.

2. For OPEX: Significantly lower cost for micro/pico cells is observed.

We wonder if other chip and equipment vendors are moving in the direction of smaller cell sizes for Fixed and Mobile WiMAX?

Figure 1. Dramatic Increases for WiFi Devices, Hot Spots, and VoIP/WiFi Phones

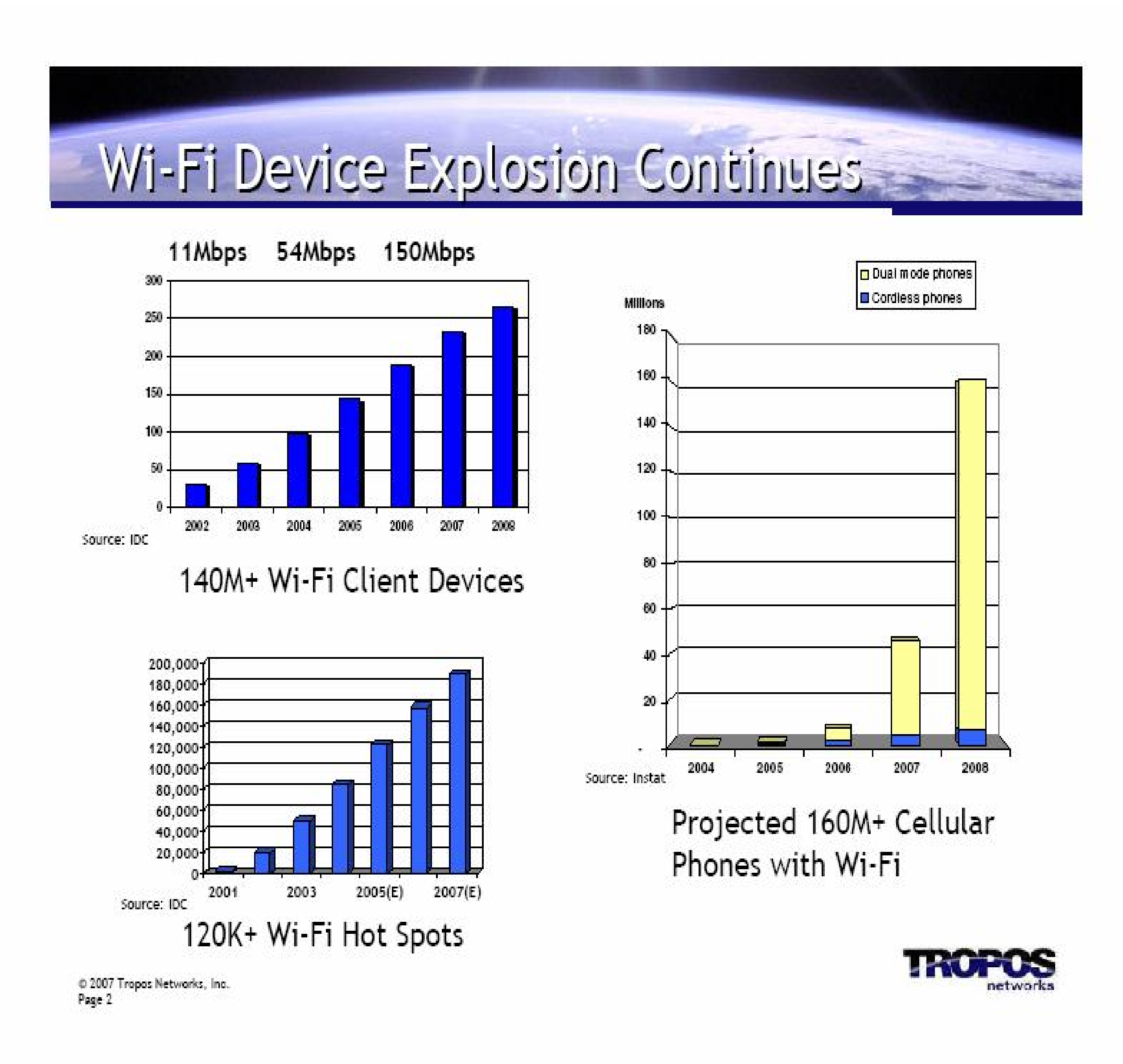

Figure 2. Cost Advantage of Metro WiFi vs 3 Competing Wireless Technologies

10% the CAPEX and 8% the OPEX of 3G

	Metro Mesh w/ Pre-WiMAX	Mobile WiMAX	1XEV-DO
Capital Cost per Home Passed	$44	$105	$66**
Operating Cost per Subscriber	$6.89	$12.24	$12.77
Subscriber Experience	1 - 5 Mbps	1 - 5 Mbps	400 - 700 kbps
CapEx / Mbps Usable Bandwidth	$15.91	$35.03	$153.05
Operating cost / Mbps usable bandwidth	$2.30	$4.08	$29.84
Concurrent Subscriber Bandwidth / Square Mile	20 - 30 Mbps	10 - 15 Mbps	1 - 1.5 Mbps
Application	Home / Mobile	Home / Mobile	Mobile

"*… cost to deliver data traffic will be a key differentiator* between service providers. [H]igher throughput…enable[s] richer, more compelling data services…"*Qualcomm whitepaper "The Economics of Mobile Wireless Data"*

Network Demographics: 100 sq miles, 200,000 households ** Does not include spectrum license costs
Source: Tropos, Airvana, Lehman Bros, Goldman Sachs, Bear Sterns, TelephonyOnLine, YankeeGroup, Industry Interviews

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