WHITE PAPER

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Building a Wireless Infrastructure: The Critical Role of Backhaul

Overview

Out of the limelight of the intense wireless debates over Wi-Fi® and cellular access technologies is the often overlooked topic of how to build the wireless infrastructure. According to Cisco Systems, in 2008 about 1.3 exabytes of data were transferred among wireless mobile devices. Furthermore, Cisco estimates that by the end of 2013 1.6 exabytes of mobile data will be transferred per month. And yet, we hardly ever hear anyone in the industry talking about how all this data makes it from the local access point back to the Internet. Somehow, it just happens and we wish it would happen faster!

Of course, the truth is it doesn't just happen. It requires significant design, operational planning, capital investment and careful execution to build up the reliable framework needed to support the vast array of connection points that we all take for granted. In fact, 30% of the operating costs for the cellular network go into backhaul costs and backhaul equipment is expected to reach $1B in revenue by 2017. Even more surprising is that 70% of the base stations use a wireless link for backhaul to the Internet. So it shouldn't come as a shock that much of the focus of network operators who must provide access over a wide area is in finding cost-effective solutions to build the infrastructure. In fact, the single biggest issue facing small cell deployments is inadequate backhaul solutions.

Continued in next column

Of course, there is the backbone of the network which includes high-capacity fiber, cable and microwave links and which is usually shared across multiple industries and service providers. Certainly, as the demand for capacity continues to skyrocket, this backbone infrastructure needs to be continually upgraded. But the real challenge, especially as we see wireless demand increasing at 20 times the rate of demand for fixed wire-line services, is meeting the high bandwidth demands at the edge of the network – what has traditionally been called the "last mile" and is now more commonly referred to as the backhaul link. This is the critical pipe that connects access points to the network and which is likely the determining factor for the overall performance of the user services provided.

This backhaul link, and particularly the wireless technologies deployed in backhaul links, is the subject of this paper. There is no question that the demand for capacity is quickly out pacing our ability to deploy new infrastructure. At the same time, the cost for basic service is rapidly decreasing while the service area is greatly expanding. Added to this conundrum are several new wireless backhaul options which encourage us to rethink conventional deployment strategies.

Banyan tree networks

We often hear networks described as tree structures with big thick trunks, smaller branches and twigs or leaves acting as access points in homes and offices. The analogy would be more accurate if it referred to Banyan trees (see Figure 1 on the following page) with their many slender and intertwined trunks holding up a canopy of intertwined branches and leaves. This image highlights several important characteristics of the network, such as its redundancy, flexibility and expansiveness. The reality is that networks are evolving toward the edge with less mass on the trunk of the trees and more cross connections along the branches. Routing and traffic shaping now occurs at nearly every node in the network in order to optimize the quality of service (QoS) and efficiency of the network. Links which were once merely transparent point-to-point pipes for data must now become smarter, more resilient and they must provide better performance.

Figure 1: Banyan tree networks

Last mile transitions to wireless backhaul

As our networks have evolved, so too have the technologies that comprise them. Quickly fading into the history books of data communications are the twisted pair phone wires we relied on for voice, dialup modem, ISDN and even T1/E1 short hauls. Twisted pair has been replaced by fiber and cable links with greater capacity for handling the increasing demand for broadcast, massive downloads and interactive services. Certainly, these new wireline solutions provide increased capacity, but they are still just point-to-point data pipes with higher costs (over $300K in OPEX over five years and longer deployment times because of the many installation barriers).

In truth, there is no perfect solution for the backhaul segment of the wireless network. Constant re-evaluation of options and technologies is needed to find the optimal solution for each deployment scenario. In general though, we can assess the technical tradeoffs in terms of four key factors: capacity, distance, flexibility and total cost of ownership (TCO). A quick summary of these tradeoffs is offered in Figure 2 on the following page.

Even within the wireless spectrum of solutions, multiple technologies must be evaluated, including TV-White Space (TVWS), Non-Line-of-Sight, Near-Line-of-Sight, Line-of-Sight and others. Each will be optimal for a certain subset of backhaul solutions, leading to the obvious conclusion that service providers will likely deploy a combination of these technologies within their network infrastructure.

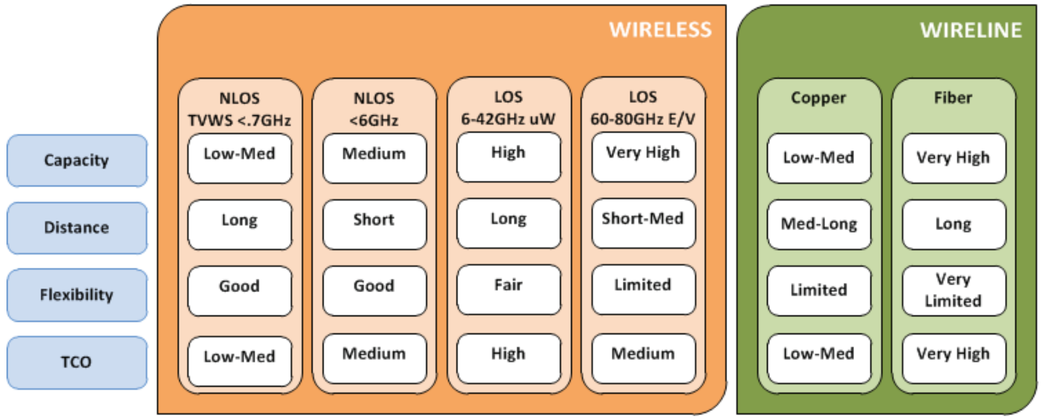

Figure 2: Backhaul technology tradeoffs

Source: "Backhaul or Small Cells," Dr. Jonathan Wells, *Mobile Experts*, November 2012

For example, if long range (up to 30km) is required but the lowest possible cost is a concern, then TVWS is likely a good option. On the other hand, if high capacity over short distances is called for, then E/V BAND microwave should be considered.

Characteristics of wireless backhaul

Perhaps the most significant characteristic of wireless data communication is its inherent flexibility, when compared to cable alternatives using fiber or copper media. Wireless backhaul does not involve miles of cables, trenches to dig, fixed endpoints or single-service provider risks. Wireless solutions involve quick deployments, open and fair access, redundant communication links, multiple service providers and a broad spectrum of solutions is available to serve every application need for both fixed and mobile devices.

This is not to say that wireless should replace wireline. Fiber cable will continue to provide the vital core infrastructure of the network; the trunks, if you will, which form the backbone of any network and which provide the key connection points for wireless backhaul. To provide a balanced Banyan tree network, the backbone infrastructure must scale in capacity to match the growing demand of the branches.

However, our focus in this paper is on last-mile access; that is, that connection segment between an access point, such as the cellular node (micro or pico cells), Internet hot-spot, remote device (machine-to-machine or smart grid), or peer access (mesh topology) and the backbone Internet network. These access points will be fixed and mobile, and we will encounter them in all aspects of our connected lives, including our homes, offices, shopping centers, campuses, parks, community centers and even in our vehicles (see Figure 3 on the following page).

Internet everywhere via wireless infrastructure

In the access domain, wireless backhaul technologies will dominate because of the cost, flexibility, TCO and capacity characteristics described previously. This is the coming of age of the ubiquitous access implied in the Internet of Things (IoT), which is driving much of the discussions in next-generation networks.

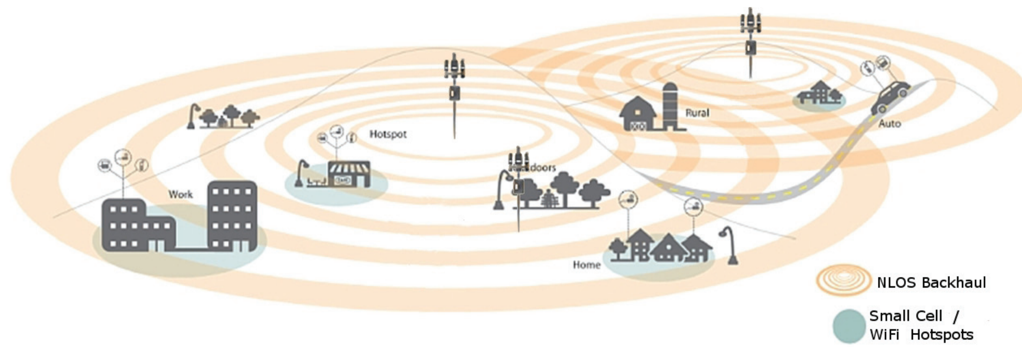

Figure 3. Last-mile access

A less talked about aspect of wireless backhaul – yet a key differentiating characteristic – is its inherent resiliency. This is especially true for networks which support the new concept of cognitive radio.

First, let's understand the problem. Any network link can fail and, in fact, they often do. A good network design plans for failure and builds in redundancy and over-capacity to handle failures, which cause traffic surges in the network segments that remain operational. The common practice has been to install redundant links in the ground. The thinking has been that as long as cable is being buried, why not install excess capacity? This is one reason why the core Internet has been able to achieve an amazing reliability record of less than one minute of outage in an entire year of service. However, this involves redundant physical cable and equipment that is expensive and it rarely extends to the access backhaul links. Consequently, it is the access point link which most often causes service outages.

A case in point was Hurricane Sandy on the East Coast of the United States when at least 20 per cent of the cellular network went offline leaving millions of people with no phone or Internet access for days. And this was one of those times when these services were most needed. Clearly, sufficient resiliency was not available in those networks to handle such a catastrophe.

Redundancy for resilient networks is essential for network access to achieve the level of reliability needed before the IoT can become a reality. Businesses as well as the general public need to know they can consistently count on network access.

For wireline networks, achieving sufficient redundancy would mean running many extra cables, or "dark fiber", on poles or in trenches. But even this would not reduce the risk of a misguided backhoe digging up a bundle of cables in one scoop or a storm knocking down a pole along with all of the cables on it. Physical and spatial redundancy (backup lines in different trenches) are needed, but this is cost prohibitive for most wired solutions, especially in the millions of last-mile links.

Wireless backhaul, on the other hand, can be very cost effective and resilient (see Figure 4 on the following page). Base stations can have multiple antennas which can be directed in any direction to connect to any other peer base station, providing many point-to-multipoint (PtMP) connections from one location. These wireless links can share (re-use) a common spectrum because they are spatially separated by the directional antennas. In addition, with cognitive radio technology, the base stations can dynamically select a different

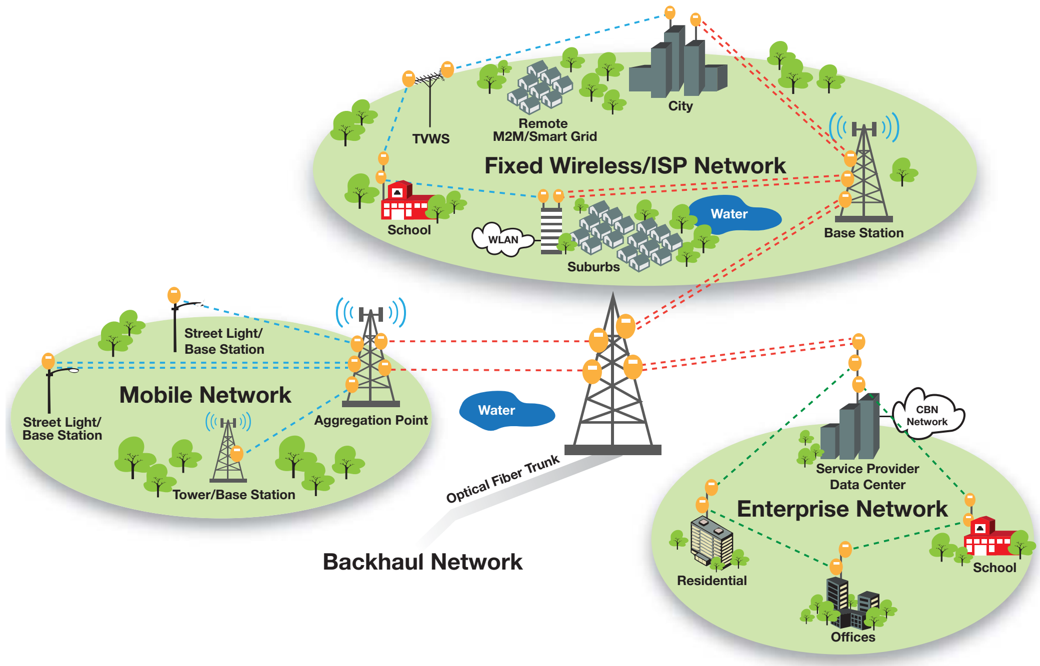

Figure 4: Wireless backhaul

spectrum range when needed to achieve spectral or physical separation to avoid signal interference. A group of base stations linked together can form a mesh network which can reroute traffic should one or more base stations fail.

This sort of multi-dimensional redundancy provides critical reliability for cellular and Wi-Fi networks and can also meet the availability requirements of mission-critical networks such as utility smart grids, public safety and emergency services.

Mesh network topology for backhaul

The last consideration for truly redundant backhaul networks is electrical power. Base stations need power, of course. If power lines are disrupted, all of the base stations on these lines are taken down, too. When this happens, there is little value in all of the other redundancies built into the base stations. Practical considerations for power redundancy very much depend on how much power is needed to operate the base station. Generally, installing gas generators for backup power at each base station is not practical! However, if a base station's power requirement is low, cost-effective alternatives are available. For example, if the base station's power budget is less than 25 Watts, redundant power can be provided over the base station's core network connection via Power-over-Ethernet (PoE) technology. Solar panels can be an option for systems requiring up to approximately 100 Watts. Of course, the key determining factor for power redundancy is the overall power consumption of the wireless equipment in the base station.

New backhaul and common platforms

Backhaul is one of many challenges facing service providers in giving us fault-tolerant, low-cost and high-performance access when and where we want it. Expanding the connected world to vast and varied geographic locations and populations is a key economic driver in all countries and for nearly all business. By 2020, wireless technologies are expected to contribute $4.5 trillion to the global economy through the expansion of existing business and the creation of new opportunities with 50 billion connected devices.

The global connected network will become an essential part of our social fabric, if it isn't already, further underscoring the criticality of a resilient, robust and fault-tolerant infrastructure. In the current state of technology, which is rapidly changing, there are no universal standards for wireless backhaul, so here lies the most critical design aspect for any equipment, adaptability.

The ability to leverage the current deployed solution to meet unforeseen future requirements; to transform and expand the scope of the initial network goals; to incrementally build upon a stable solution to extend its reach and value. This is the holy grail of wireless equipment providers and the fundamental theme behind concept of software defined radios (SDR). Building equipment that is designed to be changed and renewed with software upgrades must be an essential part of any network strategy. We already accept this reality in our computers and mobile devices. It is time to apply this logic to our network equipment as well.

Fortunately, there are processing platforms specifically designed to solve this problem by implementing many of the most demanding algorithms in dedicated accelerators or coprocessors; leaving the main processor for the variability of application code.

TI has developed an entire new family of System-on-Chip (SoC) devices providing highly integrated solutions by combining high-performance Digital Signal Processors (DSPs), ARM® processors, Packet Accelerators and Digital Radio Accelerators which will make software-defined radio (SDR) solutions practical.

For example, TI's TCI6630K2L SoC includes two high-speed ARM Cortex™-A15 host processors, four TMS320C66x DSP processors, four GigE interfaces and extensive I/O capabilities (see Figure 5). In addition,

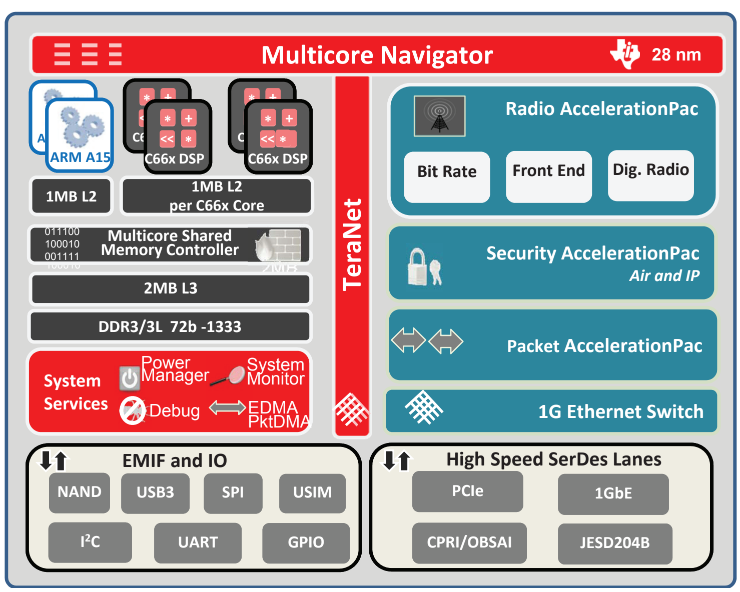

Figure 5: TI's TCI6630K2L System-on-Chip

this device includes the following Radio Accelerators implemented in silicon which offload the SDR for these CPU-intensive functions:

- Digital Radio Front End – full up/down conversion to baseband (DFE)
- Two FFT coprocessors – TDD/FDD frame muxing (FFTC)
- Four Viterbi Decoder accelerators (VCP)
- Two Turbo Decoders accelerators (TCP3d)
- Bit-rate coprocessors – up/down link processing (BCP)

This highly integrated approach provides the performance, compact SoC implementation and low-cost that is required to make SDR a reality. And the comprehensive scope of radio accelerators ensures this device will be successful in a wide range of wireless applications scenarios.

The combination of SDR and SoC technologies will enable developers and system integrators to quickly develop low-cost, low-power Cognitive Radio solutions and enable the rapid development of new applications.

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